6 Development of Alternatives

Remedial technologies and process options that were retained in Section 5 are assembled into remedial alternatives in this section. This section describes how alternatives were assembled, the remedy components for each alternative, and how the alternatives would be implemented. This section includes assumptions and conceptual design criteria used as the basis for FS-level cost estimates that are presented in Section 7 and Appendix D. Section 6.1 describes how alternatives were assembled and lists the 11 remedial alternatives developed for the Site. The alternatives include a No Action alternative (Alternative 1) to establish a baseline for comparison to the other active alternatives. Section 6.2 describes considerations and assumptions common to each alternative, and Section 6.3 describes the specific assumptions for and details of each remedial alternative carried forward for detailed evaluation in this FS.

6.1 Assembly of Remedial Alternatives

Remedial technologies and process options that were retained in Section 5 were assembled into the following alternatives. To assist the reader, descriptive titles for each numbered alternative are provided below with the areas that are the primary focus of the remedy listed in parentheses.

- **Alternative 1 – No Action**
- **Alternative 2 – Containment:** permeable soil, engineered sand, and RCM sediment capping
- **Alternative 3 – Targeted PTW[1] Solidification (RR and MC-1 DNAPL Areas):** targeted treatment of two areas of deep upland PTWs via *in situ* solidification, passive groundwater treatment, and soil and sediment capping
- **Alternative 4 – Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of three areas of PTWs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 4a – Targeted PTW Solidification (QP-U, RR and MC-1 DNAPL Areas) and Removal (TD DNAPL Area):** targeted treatement of two areas of deep upland PTWs and one nearshore upland PTW area via *in situ* solidification, targeted treatment of one area of sediment PTWs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 5 – Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S**

[1] PTWs for the Site include DNAPL, DNAPL-impacted soil, and DNAPL-impacted sediment (see Section 4.2). Upland PTWs include DNAPL and DNAPL-impacted soil located east of the shoreline. Sediment PTWs include DNAPL and DNAPL-impacted sediment west of the shoreline.

DNAPL Areas): targeted treatment of multiple upland areas of PTWs via *in situ* solidification and targeted removal/off-site disposal of sediment PTWs, passive groundwater treatment, and soil and sediment capping

- **Alternative 6 – Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of multiple upland areas of PTWs via *in situ* solidification and targeted removal/off-site disposal of upland and sediment PTWs, passive groundwater treatment, and soil and sediment capping
- **Alternative 7 – PTW Solidification (Upland) and Removal (Sediment):** treatment of all upland PTWs via *in situ* solidification, treatment of all sediment PTWs via removal/off-site disposal, and soil and sediment capping
- **Alternative 8 – PTW Removal (Upland and Sediment):** treatment of all upland and sediment PTWs via removal/on-site *ex situ* thermal treatment, and soil and sediment capping
- **Alternative 9 – Solidification and Removal of Upland PTW and Contaminated Soil, and Removal of Sediment PTW and Contaminated Sediment:** treatment of all upland PTWs and contaminated soil via *in situ* solidification or removal/on-site *ex situ* thermal treatment, treatment of all sediment PTWs and contaminated sediment via removal/on-site *ex situ* thermal treatment, and soil and sediment capping
- **Alternative 10 – Removal of Upland PTW, Sediment PTW, Contaminated Soil, and Contaminated Sediment:** treatment of all PTWs and contaminated soil and sediment via removal/on-site *ex situ* thermal treatment, and soil and sediment capping

The alternatives were assembled to provide a broad range of actions, including various levels of containment and treatment, consistent with EPA guidance (EPA 1988a).

The technologies and process options that make up each alternative (i.e., the remedy components) are summarized in Table 6-1. Estimated construction quantities are summarized in Table 6-2.

Not all remedial technologies or process options that were retained in Section 5 as potentially applicable to the Site were included in the range of alternatives. Examples include *in situ* bioremediation of soil and biosparging of groundwater. While these are potentially viable polishing technologies, other viable polishing or *in situ* treatment technologies were selected for the purposes of the FS (for example, groundwater pump-and-treat in Alternative 10). It is expected that selection of the most appropriate process option, such as the type of reactive media used in reactive containment and treatment technologies, would occur during remedy design.

6.2 Common Elements

This section describes considerations that are common to the all alternatives, except Alternative 1 – No Action. These include assumptions regarding potential redevelopment of the Quendall Terminals Property (Section 6.2.1), future habitat considerations (Section

6.2.2), assumptions regarding the potential generation of hazardous waste during remediation (Section 6.2.3), a summary description of predictive numerical and analytical modeling tools used to support development and evaluation of alternatives (Section 6.2.4) and certain remedial elements common to all alternatives, specifically institutional controls (Section 6.2.5) and monitoring (Section 6.2.6).

6.2.1 *Redevelopment of the Quendall Terminals Property*

The Site is currently vacant and unused. The Quendall Terminals Property is likely to be redeveloped once a remedy is selected and implemented. Based on Site zoning and the most recent development plan, a future development is expected to include the following features, which were considered in developing alternatives:

- Future grade would likely be higher to meet the grades on adjacent properties and to allow installation of a gravity sewer system. As a result, excess material that may be generated during some remedies (e.g., an increase in soil volume during solidification) can likely remain on the Site.
- Site development would likely involve installation of structures such as buildings and utilities that may limit or prevent access to left inplace contamination or remedial components. If additional remedial measures are needed in the future, the presence of these structures may also prevent additional remedial activities to be put in place or limit the scope or type of remedial measures that can be implemented.

Post-remediation Site development is assumed to include impermeable[2] engineered surfaces, such as roadways, sidewalks, parking lots, and building foundations. Future buildings would likely include deep foundation elements (e.g., driven pilings) that would be designed to ensure they are compatible with cleanup, as discussed below.

As discussed in the Site CSM (see Section 3), most DNAPL in the subsurface does not appear to be actively migrating. Future site development construction activies and the existence of a permanent development infrastructure have the potential to modify conditions that affect DNAPL mobility and potentially cause DNAPL to migrate, as follows:

- Reductions in stormwater infiltration from placement of impermeable surfaces related to future development would reduce hydraulic head and leaching, and may reduce DNAPL migration potential.
- Placement of fill has the potential to compress certain underlying soils such as peat, which could mobilize fluids present in those soils; however, compressible soils at the Site (e.g., peat) are low-permeability soils that limit DNAPL migration but do not contain significant quantities of DNAPL themselves.
- Installation of deep foundation elements can create preferential pathways for DNAPL migration. To limit this possibility, construction techniques that

[2] However, future "green" development regulations may require that some surfaces such roads and sidewalks be constructed of permeable or semi-permeable materials.

allow installation of foundation elements in a manner that does not provide preferential pathways (e.g., use of displacement pile technology) would be implemented in DNAPL areas as appropriate.

6.2.2 *Habitat Considerations*

It is anticipated that it would be necessary to fill on-site wetlands to complete the Site cleanup and as a result, mitigation would be required pursuant to Clean Water Act (CWA) Section 404(b)(1). EPA has determined that filling the wetlands cannot be avoided or minimized, and as a result mitigation is required. EPA has identified the entire Quendall shoreline and landward 100 feet as the habitat corridor that will be the location for wetland mitigation. It is also anticipated that it would be necessary to disturb substantial existing shoreline habitats within and waterward of the 100-foot shoreline area to complete the Site cleanup and as a result, mitigation could also be required pursuant to ESA. For purposes of evaluating FS alternatives, it is assumed that an area along the shoreline (the habitat area, see Figure 6-1) would be used for mitigation following cleanup and would remain undeveloped. This FS contains, in Appendix G [Final Baseline Wetland and Habitat Report], the site information required pursuant to the CWA to establish habitat and wetland baseline conditions. Also, Appendix G contains information according to CWA 404(b)(1) and its regulations that define the jurisdiction, delineation, and ranking of each on-site wetland. Habitat mitigations plans will be developed in the remedial design phase of the cleanup process. All of the alternatives in this FS, except Alternative 1, take into account the CWA 404(b)(1) statute and its requirements and all such alternatives included provisions for future habitat mitigation along the Quendall shoreline. Habitat mitigation pursuant to the CWA or the ESA would be included as part of the remedy.

Remedial components planned and/or selected for the habitat area would need to consider potential access and use limitations. Accordingly, some potential remedial components of the FS alternatives may not be compatible with future habitat areas. For example, repair and replacement of RCM sediment caps along the shoreline would require periodic use of heavy equipment that would cause serious degradation of the habitat area unless EPA, the Muckleshoot Tribe, and Trustees agreed that access for purposes of installation, operation, and maintenance were acceptable. This is considered in the evaluation of alternatives. Depending on the location of future wetland areas along the shoreline, the potential for contaminated groundwater to discharge into wetland habitat areas and impact biota would need to be evaluated.

The habitat needs of juvenile Chinook salmon would be an important focus when evaluating alternatives and developing the mitigation plan during remedy design. The mitigation plan will be developed and approved in concert with EPA, the Trustees, and the Muckleshoot Tribe.

For the purposes of the FS, the following assumptions regarding habitat were made:

- The habitat area would consist of a 100-foot-wide corridor along the shoreline and be composed of a mixture of wetlands and riparian habitat. Remedial components requiring future access for monitoring or maintenance, such as permeable reactive barriers (PRBs) or groundwater extraction wells, would be placed outside and east of the habitat area.

- Caps in the habitat area could require clean material to a minimum depth of 3 feet below current grade, to allow for creation of wetlands and to provide an adequate root zone for future plants or excavation/dredging of all DNAPL within the habitat area could be implemented.
- In-water work, such as sediment capping, dredging, backfilling, and sheet pile installation, would occur during the allowable in-water work window, which currently extends from July 16 to December 31 annually. However, dredging within sheet pile enclosures could occur outside of the in-water work window as the sheet pile isolates the dredge area from the lake.
- Remedy implementation would result in no net loss of aquatic habitat or function. For most alternatives, this is accomplished to maintain the existing location of the OHWM and the existing bathymetry near the shoreline. For alternatives with sediment caps along the shoreline, existing sediment would be removed to offset the cap thickness from the OHWM to approximately 75 feet offshore.

6.2.3 *Potential Generation of Hazardous Waste during Remediation*

K035 RCRA wastes may be generated by remedial activities that remove soil above the water table in the footprint of the North and South Sumps. In addition, D018 RCRA wastes (benzene exceeding 0.5 mg/L toxicity characteristic leaching procedure [TCLP]) and WP01 state dangerous wastes (total PAHs exceeding 1 percent by weight) may be generated by remedial activities that remove soil or sediment containing DNAPL. For the purposes of cost estimating, the following assumptions have been made:

- Soil located above the water table within the footprint of the North and South Sumps, if removed, would designate as a K035 RCRA waste and would be disposed of at a RCRA Subtitle C landfill if transported off site.
- PTW soil, if removed, would designate as a D018 and/or WP01 waste, and would be disposed of at a RCRA Subtitle C landfill if transported off site.
- Other soil would not designate as a RCRA or Washington State dangerous waste.
- Dredged sediment would not designate as a RCRA or Washington State dangerous waste. Based on a review of available sediment data, most of the sediment has concentrations of total PAHs or benzene less than the RCRA and Washington State dangerous waste criteria.It is assumed that dredging, handling and dewatering would dilute concentrations in the removed sediment so that all material for disposal would not designate as a RCRA or Washington State dangerous waste.

Based on the maximum concentration of benzene (4.8 mg/kg at boring RB9), it is not anticipated that any soil generated would exceed 10 times the Universal Treatment Standard (UTS) of 10 mg/kg (i.e., 100 mg/kg); therefore, it is assumed that PTW soil would not require treatment prior to disposal at a RCRA Subtitle C landfill (40 CFR 268.49[c]). However, depending on the volume of material to be disposed of and other factors, it may be cost-effective to treat soils that would otherwise be designated as D018 and/or WP01 waste to remove the toxicity characteristic so they may be disposed of at a lower-cost RCRA Subtitle D landfill. This is an option that could be evaluated during remedy design.

DNAPL is often found in thin layers (i.e., stringers) that could not be "surgically" removed from surrounding soil that does not contain DNAPL. Excavation of these stringers and surrounding soil could result in either an increase (based on an increase in the volume of PTW soil) or decrease (based on the dilution of PTW soil with soil containing lower contaminant concentrations) in the hazardous waste volume. For purposes of this FS, the soil volume potentially being designated as D018 or WP01 is based on the estimated thickness of PTW soil and not adjusted based on potential dilution or inclusion of surrounding soil.

6.2.4 *Modeling Tools Used in Alternative Development*

Groundwater and sediment cap modeling were used to help develop alternatives in two ways: 1) to evaluate how site-wide alternatives could be structured to meet RAOs and 2) to provide conceptual design criteria for the purpose of developing alternatives and estimating costs. Details of model setup, results, and sensitivity analysis are discussed in Appendices A and B. A summary of the model setup for each alternative is provided below.

6.2.4.1 Groundwater Flow and Fate and Transport Model

The numerical groundwater flow and fate and transport model described in Appendix D of the RI Report (Anchor QEA and Aspect 2012) was refined to develop and evaluate remedial alternatives in this FS. The refinements to the RI groundwater model to support its use in this FS are presented in Appendix A.

For the FS analysis, the FS groundwater model was initially set up using the same grid and input parameters used for the RI, with the following refinements:

- The grid was adjusted to accommodate particular remedy components (for example, to simulate solidified soils at a higher vertical resolution);
- Boundary conditions were adjusted and added/removed to simulate upland caps, PRBs, slurry walls, and removal of DNAPL; and
- Groundwater flow parameters were adjusted to simulate changes to aquifer properties associated with backfill placement and soil solidification.

In addition, to assist in developing alternatives, the Site-wide distribution of key indicator COCs and the effect of various remedial components were evaluated in a three-step process. First, source areas were identified as follows:

Model grid cells representing the distribution of DNAPL observed at the Site were identified as a source of contamination (referred to in Appendix A as a constant concentration boundary in the model) of benzene, naphthalene, and benzo(a)pyrene in groundwater. An average concentration[3] of naphthalene (11,000 µg/L) and benzo(a)pyrene (133 µg/L) were assigned to the model grid cells "containing" DNAPL. Because benzene concentrations vary widely in DNAPL areas based on the type of DNAPL, average concentrations were defined for each of three different areas of the Site as follows:

- 1,100 µg/L in the eastern portion of the former May Creek Channel Area, former Railroad Tank Car Loading Area, and former Still House Area (wells BH-25A[R] and Q9);
- 200 µg/L in the North Sump Area (wells BH-23 and RW-NS-1); and
- 12,000 µg/L in the QP-U DNAPL Area, (wells BH-5, BH-19, BH-20A, and RW-QP-1).

Model grid cells containing DNAPL in the Solid Materials Loading Area were not identified as a constant concentration boundary because benzene, naphthalene, and benzo(a)pyrene were not detected in this area. Model grid cells around well BH-21A were also not identified as constant concentration boundaries because benzene was detected at a concentration of 4 µg/L, below the MCL of 5 µg/L. Model grid cells not containing DNAPL were similarly not identified as a constant concentration boundary.

Second, after establishing the constant concentration boundaries, the FS groundwater model was run for 100 years to simulate the potential contaminant fate and transport from hydrocarbon source areas (i.e., DNAPL) that has occurred since the beginning of Site operations.[4] This provided a model-predicted "representation" of the extent of contamination (i.e., pre-remedial action condition) of hydrocarbons across the Site.

Because no soil source of arsenic has been identified at the Site, pre-remedial action conditions for arsenic were identified based on groundwater empirical data reported in the RI Report (Anchor QEA and Aspect 2012) and are described below:

- In areas with concentrations below the MCL for arsenic (10 µg/L), the pre-remedial action condition was set at the state background concentration of 5 µg/L; and
- In areas with concentrations exceeding the MCL for arsenic (10 µg/L), as shown on Figures 3-6 and 3-7, the pre-remedial action condition was set at the average arsenic concentration[5] detected in these areas (39 µg/L).

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[3] Average of concentrations reported on Figure 5.2-8 of the RI Report at wells within DNAPL areas: BH-5, BH-19, BH-20A, BH-21A, BH-23, BH-25A(R), Q4, Q9, RW-NS-1, and RW-QP-1. Non-detected concentrations were not included.

[4] As discussed in more detail in Section 7, one hundred (100) years was assumed for purposes of estimating O&M and monitoring costs.

[5] Average arsenic concentration at wells BH-5, BH-5A, BH-5B, BH19, BH-20B, BH-21B, BH-25AR, BH-26B, and BH-28B was used. The concentration detected at well Q9, 1,960 µg/L, was not included as it is suspected that the sample from this well was based on the presence and potential entrainment of DNAPL in the sample (see Section 5.2 of the RI Report, Anchor QEA and Aspect 2012).

Finally, to evaluate the effect of implementing a particular remedy component, the FS groundwater model was modified to simulate the remedial action (e.g., removal of an area of DNAPL or construction of a PRB), and then run for another 100 years to provide a model-predicted future extent of contamination (i.e., post-remedial action condition).

Because of limitations and constraints inherent in the application of predictive models to represent a physical system (e.g., simplifications of subsurface conditions, use of average source concentrations, and approximation of contaminant fate and transport parameters), the model-predicted results (e.g., extent of contamination) are approximations of actual Site conditions. While the FS groundwater model was calibrated to represent overall Site conditions, the model cannot exactly match the current Site conditions, especially on relatively small spatial scales; however, the FS groundwater model provides an appropriate basis for evaluating, on a relative basis, how a particular remedial action may change conditions and how different remedial actions compare. In addition to the groundwater modeling described in this section, the FS groundwater model was also used as part of this FS to evaluate and compare remedial alternatives, including estimating changes in groundwater contamination plume volume and groundwater restoration timeframe, as described in Sections 7 and 8.

6.2.4.2 Sediment Cap Modeling

The remedial alternatives include an engineered sand cap. A conceptual engineered sand cap design was developed for the FS based on assessments of cap stability and 1-dimensional numerical modeling of chemical attenuation within the cap (i.e., the model developed by Dr. Danny Reible from the University of Texas as described in Lampert and Reible 2009; hereafter referred to as the UT Model). The UT Model evaluations are discussed in detail in Appendix B. A brief summary of the UT Model is provided below.

The UT Model was used to evaluate the long-term performance of a sediment isolation cap. The UT steady-state model estimates the chemical concentrations vertically throughout a cap, including the surficial (bioturbation) layer, once steady-state conditions are achieved in the cap. As the dissolved contaminants move upward through the cap, they may undergo degradation and may partition onto the cap material. The UT Model simulates bioturbation, which mixes the surface layer, further reducing surface concentrations (Lampert and Reible 2009). The UT Model calculates the contaminant concentrations in the bioturbation layer as a balance between the flux from the underlying ntaminant isolation layer, the flux associated with bioturbation processes, and the flux leaving the benthic boundary layer that enters the overlying water column.

The chemical isolation layer modeling was first applied to measured sediment porewater cation profiles at the Site, using validated Site characterization data presented in the RI Report (Anchor QEA and Aspect 2012). The model in this application provides a useful analytical framework to help differentiate the combined effects of a range of physical processes (e.g., advection and dispersion) from chemical and biological degradation processes for Site COCs.

Once calibrated, the UT Model was used to simulate the conditions for the proposed sand cap area. Predictions of nearshore seepage velocity from the FS groundwater model (Appendix A) were used as input to the sediment model. The results indicate that an isolation cap composed of 1.5 feet of sand in the nearshore area would sufficiently reduce contaminant flux such that surface sediment porewater/surface water PRGs (Table 4-6) would be achieved under steady-state conditions (Appendix B). Additional discussions of cap effectiveness are presented in Section 7.

6.2.5 *Institutional Controls*

The institutional controls will be an important part of the overall cleanup at the Site, especially since contamination that exceeds cleanup levels will remain onsite for all alternatives to varying degrees. Institutional controls may be applied during remedy implementation to minimize the potential for human exposure (as temporary land use or exposure limitations). These controls may also extend beyond the end of construction (or be created at that time) or even after cleanup objectives are achieved to ensure the long-term protectiveness of remedial actions that leave contaminants on-site above cleanup levels (as long-term or permanent limitations, e.g., protecting sediment caps from being accidentally breached). EPA recommends that where it may provide greater protection, multiple institutional controls should be used in combination, referred to as “layering” by EPA.

The following is a summary of the array of instititional controls that could be used at Quendall, depending on the type of exposures that could result from contamination left in place or to protect engineering controls, such as sediment caps, that are meant to prevent exposures from the contamination left in place. More details about the need, use, and implementation of institutional controls will be delineated through the ROD and possibly supplemented with more specifics in remedial design and remedial action.

6.2.5.1 Government Controls

Government controls use the regulatory authority of governmental entities to impose restrictions on citizens or property under its jurisdiction. Governmental controls, such as zoning and the permitting discharges to Lake Washington, or filling of wetlands, are not described further in this section because they do not inform the choices among alternative remedies (i.e., zoning and permitting requirements cannot be changed by remedy selection in the ROD). Government controls utilized for Quendall may include:

- **Fishing and swimming bans.** Restrictions that ban fishing and swimming are established by state departments of health or other governmental entities through coordination with EPA.
- **Notification of Waterway Use.** Notifications may need to be used to provide notice to vessel operators to prevent damage to caps, *in situ* treatment, ENR, or other remedy components. Notification to waterway users could further be provided through enhanced signage and other forms of public notice, education, and outreach (i.e., information devices). These would include:
    - Restrictive anchorage within the areas that are capped;
    - Restrictive grounding of small vessels on the shoreline;
    - Restrictions of vessel draft, horsepower, speed, and time in area; and

  - Restrictions on piling placement or removal through cap, or other potential in-water construction/structures.

6.2.5.2 Proprietary Controls

Proprietary controls are recorded rights or restrictions placed in deeds or other documents transferring property interests that restrict or affect the use of property. They include covenants (grants or transfers of contractual rights) and easements (grants of property rights by an owner. Covenants and easements are essentially legally binding arrangements that allow or restrict usage of property for one or more specific objectives (e.g., habitat protection, protection of human health, etc.). They commonly survive the transfer of properties through real estate transactions and are binding on successors in interest who have not participated in their negotiation. They can be implemented without the intervention of any federal, state, or local regulatory authority. At cleanup sites, environmental covenants and easements commonly control or prevent current and future owners from conducting or allowing activity that could result in the release or exposure of buried contamination as long as necessary.

Environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands would be filed with King County. Covenants may be placed on state-owned aquatic lands through a long-term agreement with the DNR. These covenants would prohibit Site activities that would interfere with the integrity of remedial actions (such as soil and sediment caps) or compromise protection of human health and the environment. Specific Site use restrictions and requirements identified in the environmental covenants may include the following:

- Protection of engineering controls such as soil and sediment caps by limiting activities which may damage the caps or increase the potential for exposure, including:
  - Upland construction activities such as excavation; and
  - In-water vessel activities (e.g., anchoring, spudding, or vessel maneuvering) and construction activities (e.g., dredging, or pile driving/pulling);
- Evaluation of vapor intrusion potential and/or construction of vapor controls for future buildings located above areas containing volatile COCs;
- Implementation of a construction management plan specifying monitoring and material management requirements for subsurface activities that would contact potentially contaminated media;
- Use of construction techniques that minimize the potential vertical mobilization of DNAPL or dissolved-phase contaminants for future deep foundation elements potentially penetrating areas of DNAPL. Such techniques may include use of displacement piles. Specific foundation elements and construction techniques would depend on geotechnical requirements for future structures; and
- Prohibition on future use of groundwater for drinking or other domestic purposes and on construction of wells (other than for remediation or monitoring purposes).

Easements may also be needed to ensure access to remedy components such as PRBs or monitoring wells.

Traditionally, covenants or easements were only enforceable by whomever they were granted to, and their successors, depending on how they were crafted. In Washington State, MTCA gave Ecology the right to enforce covenants created under MTCA. More recently, Washington passed its Uniform Environmental Covenants Act (UECA), which allows EPA, as well as the state (in addition to the parties to an UECA covenant), to enforce environmental covenants. For this reason, UECA covenants are anticipated to be the primary proprietary control used for the Quendall Site.

6.2.5.3 Enforcement and Permit Tools

Enforcement tools include legal administrative orders, permits, and consent decrees that limit certain Site activities or require the performance of specific activities (e.g., to monitor and report on an institutional controls' effectiveness). These tools are not discussed at any depth in this FS because they do not inform the choices among alternative remedies.

6.2.5.4 Informational Devices

Information devices are tools that would rely on property record systems to provide the public with information about risks from remaining contamination at the Site. They may discourage inappropriate land use, but are not legally enforceable. For Quendall, they may include:

- **Deed Notices.** These are notices that provide information in public land records to alert persons regarding property conditions, including the type of contamination present and associated risks and activities that could result in exposure to contaminants left on the Site.
- **Advisories, Public Outreach, and Education.** The Washington State Department of Health (WDOH) publishes seafood consumption advisories in Washington. The WDOH currently recommends limits on Northern Pikeminnow, Carp, Cutthroat Trout, and Yellow Perch in Lake Washington. There is also advice on consumption of Sockeye Salmon, Rainbow Trout, and Pumpkin Seed as well.
- **The Washington State Department of Fish and Wildlife (WDFW)** develops and enforces seasonal restrictions on recreational fishing and seasonal and daily catch limits per individual for various seafood species. WDFW licensing and enforcement activities presumably limit resident Lake Washington seafood consumption to some unknown degree. While WDFW regulations summarize the WDOH seafood consumption advisories, which may enhance their reach and effectiveness, they do not prohibit fishing or shellfishing within Lake Washington. It is lawful to seasonally collect and consume certain fish and shellfish from Lake Washington.
- **Environmental Covenants Registry.** Placement and maintenance of Quendall areas, with containment remedies (upland or sediment caps) or anywhere where contamination remains above levels needed to meet cleanup objectives, on Ecology's Environmental Covenants Registry in its Integrated Site Information System) would provide information regarding applicable

restrictions (RNAs and proprietary controls) to anyone who uses or consults the state registry.

6.2.5.5 Institutional Controls Summary

At Quendall, the larger the volume of contamination left in place in multiple media, using multiple remedial technologies to protect a variety of exposure pathways for humans and terrestrial and aquatic wildlife, the more complex and extensive the type and use of institutional controls will be and the more likely a wider range of institutional control effectiveness and reliability can be expected. At Quendall, remedial actions will need to remediate virtually all exposure pathways to humans and aquatic and terrestrial organisms.

6.2.6 *Monitoring*

Long-term monitoring would be conducted to confirm that the remedy is functioning as intended and according to the performance criteria established in the ROD and the Operation, Maintenance and Monitoring Plan (OMMP). The monitoring program would be developed to include specific objectives, a plan for assessing those objectives, and the methods to be used in implementing the plan. For Alternatives 2 through 6, most monitoring will be required in perpetuity because hazardous substances will be left in place. For Alternatives 7 through 10, where it is expected extensive treatment or removal of hazardous substances will take place, long-term monitoring will be much more limited. After remedial action is completed, a monitoring plan will be prepared that will reflect the extent to which hazardous substances have been left on-site.

Each alternative relies on an array of technologies when combined constitute an alternative. For the Quendall FS, the array of alternatives begins with remedies that rely primarily on capping, and as each additional remedy becomes more aggressive in removing or treating PTWs or other contaminated media, the necessity for monitoring decreases.

The extent of contamination left in place after remediation will be the major determinant regarding the extent of monitoring necessary to ensure that the remedy is functioning as intended and remains protective.

At the Quendall site, monitoring will require at a minimum the following:

- Inspection of upland cap integrity and sampling to determine whether uncapped areas remain below cleanup levels.
- Bathymetric surveys to assess the integrity of sediment caps and covers and sampling to determine whether the sediment remedy continues to function as designed and meets performance criteria.
- Groundwater monitoring for site COCs to determine whether the PRB and/ or DNAPL trench collection systems are functioning as intended and to assess the interim performance of the Quendall remedy.

The frequency and extent of monitoring will be determined and documented in an OMMP developed near the completion of remedial design. Monitoring requirements will reflect the extent to which contamination is left on-site, the reliability of engineering controls, repair/replacement frequency, etc. For Alternatives 2 through 6, monitoring is expected to be required in perpetuity. The frequency and degree of monitoring is not expected to decrease over time because of the magnitude of contamination left in place. Frequency of sampling can assumed to be at least annually due to the risks associated with remedy failure. All of the above would also be conducted after significant natural events, such as earthquakes. Five-year reviews will be required in perpetuity and will require a more robust monitoring regime.

Short-term monitoring would be conducted during remedy construction. In-water work such as ENR and capping must occur during the allowable in-water work window and would require water quality control measures and water quality monitoring. Upland remedial measures that include disturbance of contaminated soil (for example, overexcavation of soil near the shoreline for habitat construction) would require a soil management plan and may require air monitoring. For each element of work, a construction quality assurance plan would be prepared following design to establish procedures for environmental monitoring during construction and to provide procedures for confirming that remedial components are constructed and documented with an appropriate level of quality assurance and quality control. As with long-term monitoring specific requirements will be determined near the completion of remedial design.

6.3 Detailed Description of Alternatives

This section describes each of the 11 alternatives, including remedy components and how each component would be implemented. Many of the details of the alternatives (e.g., extent of excavation or solidification) presented in this section are preliminary design criteria developed using existing information. The preliminary design criteria are used to estimate remedial costs and to develop and compare remedial alternatives. Remedial area and material volume estimates are summarized in Table 6-1. Calculations for estimated quantities are provided in Appendix E.

Depending on the remedy ultimately selected by EPA, additional information may need to be collected during remedial design, which would be used to refine quantities and other design details. For example, additional explorations may be performed during remedial design to refine the extent of materials targeted for removal or treatment. In addition, bench- or pilot-testing may be performed during remedial design to optimize solidification amendments, reactive materials in RCM sediment caps and the PRB treatment media, and/or sediment cap designs. Additional data gathering to support remedial design would be conducted as necessary after a remedy is selected.

6.3.1 *Alternative 1 – No Action*

Per EPA guidance, this No Action alternative (Alternative 1) is included to provide a baseline for comparison to other active alternatives. Under Alternative 1, there would be no cleanup, institutional controls or monitoring, or associated land use actions.

6.3.2 *Alternative 2 – Containment*

Alternative 2 combines ENR of sediments, soil and sediment capping, and institutional controls to prevent exposure to contaminated media. This alternative includes maintenance of engineering controls and monitoring of all media to confirm that exposure pathways are controlled. Specific remedial components include the following:

- ENR to remediate areas of low concentrations of cPAHs in sediment;
- Engineered sand cap to remediate areas impacted by upwelling contaminated groundwater;
- RCM cap in PTW areas to sorb DNAPL and control DNAPL migration;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

A description of the remedial action components comprising this alternative is provided below and summarized in Table 6-1. A schematic showing the layout of alternative components is provided on Figure 6-1. Subsurface components of this alternative are illustrated along representative cross sections on Figures 6-2 and 6-3.

6.3.2.1 Alternative 2 Enhanced Natural Recovery

ENR would consist of a 6-inch (approximately 15 cm) thin sand layer placed over the sediments in the offshore area of Lake Washington. ENR would be applied in areas of sediment beyond the nearshore zone of upwelling groundwater, where the BTV value is slightly (e.g., less than twice) exceeded. ENR would provide a surface layer of clean material, resulting in an immediate reduction in surface chemical concentrations. ENR would facilitate the re-establishment of benthic organisms.

The ENR material would likely consist of fine-grained to medium-grained sand and would be placed from a barge. Depending on the source of the sand material, it may be barged or trucked to the Site. Two methods of applying ENR used previously at other sites include hydraulic washing from the deck of a barge (effective for dispersing a thin-layer cap over a large area) or window placement from a split-hull hopper dredge. Specialized approaches for placing caps in thin lifts such as a spreader box may also be used. ENR may have limited, short-term water quality impacts due to the suspension of the ENR material in the water column.

As detailed in Appendix E, the estimated volume of ENR material placed would be 14,300 cy. Based on an assumed cap placement production rate of 500 cy per day, ENR would require approximately 6 weeks to implement.

6.3.2.2 Alternative 2 Engineered Sand Cap

The engineered sand cap would consist of approximately 1.5 feet of sand placed over the existing sediment surface where groundwater is upwelling and exceeds the groundwater PRGs. In addition, a geotextile layer may be placed between the sand and the existing sediment surface to demarcate clean material from underlying contaminated sediments in the nearshore area and provide separation between the cap material and the underlying soft sediment. Without a geotextile layer, the sand may initially sink into the soft sediment. A geotextile layer would also increase cap stability during and following placement. However, installation of geotextile layers in aquatic environments can be challenging and would be further evaluated in the design. For the FS, it is assumed a geotextile layer would be placed within approximately 75 feet of the shoreline as a demarcation layer, and that a geotextile layer would not be placed under the offshore portions of the sand cap.

The sand cap would provide a clean bioturbation layer and would also reduce surface sediment porewater concentrations relative to deeper groundwater concentrations, ensuring the cleanup numbers would be achieved in surface sediment under steady-state conditions (see cap modeling results in Appendix B). The engineered sand cap would be placed in the nearshore area, excluding the PTW sediment areas. The sand cap extent would encompass the area where porewater data exceeds PRGs (outside of the PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV.

Whether any of the capped shoreline areas would require erosion protection would be determined in remedial design. However, for the purposes of the FS and cost estimation, erosion protection is assumed conservatively. The assumption is that a shoreline cap in less than 15 feet of water depth would require erosion protection from wave energy and vessel-generated current. A preliminary evaluation regarding cap stability indicates that the estimated armor size required is material with a median diameter of 6.0 inches (i.e., rip-rap) for breaking waves (0 to 5 feet of water depth), or a median diameter of 0.6 inches (i.e., gravel) for non-breaking waves. Appendix B (B-3) provides additional details regarding FS-level cap stability design calculations and conceptual material specifications for various cap layers. Further assessment regarding the need for armoring will be conducted in remedial design. If additional extensive analysis reveals that armoring that is not suitable for habitat is needed to prevent erosion, then capping may not be an acceptable remedial approach for alternatives that include shoreline capping. As an alternative to rip-rap, biotechnical stabilization (erosion protection which enhances habitat features) would be evaluated during the design. For example, a cellular confinement layer (e.g., geocell, Geoweb®, StataWeb™) and vegetation may be used to protect the sand cap surface. The use of a geocell technology generally reduces the required particle size of the armor material by providing material confinement within the cells. However, the installation of geocells in aquatic environments can be challenging and requires further evaluation in design.

From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to maintain the existing elevation and profile of the nearshore area (i.e., 1.5 feet of sediment). Removal of sediment would likely be conducted using mechanical removal equipment either from a barge or from the shoreline. Sand would likely be placed using specialized capping delivery approaches such as a spreader box to provide a thin lift of material. The sand may be placed in two to three thinner lifts. To the extent practicable, nearshore erosion protection would be placed with land-based equipment. The removed sediment would be dewatered and disposed of as described in Section 6.3.3.2.

As detailed in Appendix E, the estimated volume of sediment dredged would be 2,200 cy, and the estimated volume of sand cap material placed would be 15,300 cy. Based on an assumed cap placement production rate of 500 cy per day and dredging rate of 400 cy per day, the sand cap would require approximately 7 weeks to implement.

6.3.2.3 Alternative 2 Reactive Core Mat Caps

As shown on Figure 6-1, all aquatic DNAPL areas (DA-1 through DA-8) would be capped with a RCM cap. The objective of the RCM cap in this alternative is to sorb any disturbed DNAPL using a relatively thin reactive cap in areas where DNAPL is relatively limited in volume, is expected to be relatively immobile due to weathering (e.g., in the T-Dock area) or where the shoreline bathymetry needs to be maintained to avoid mitigation for loss of aquatic habitat.

The RCM cap would consist of an organoclay RCM overlain by 6-inches of clean sand to provide a bioturbation layer. The RCM consists of an approximately ¼-in-thick organoclay layer sandwiched between two geotextiles layers stitched together. Along the shoreline in areas with less than 15 feet of water depth, additional analysis will be required during remedial design to determine whether erosion protection is needed and, if so, the necessary specifications of erosion protection material needed to maintain stability. However, for the purposes of the FS and cost estimation, the need for erosion protection is assumed. In addition, the RCM layer would be permanently secured on the banks using an anchoring system.

For the FS, based on the assumed stability of the DNAPL, one layer of RCM is assumed for the reactive cap. A standard RCM includes approximately 0.8 pound of organoclay per square foot (ft^2) and is supplied in 1,500-ft^2 rolls (15 feet by 100 feet). It is assumed that a minimum of 1-ft of overlap between mats would be required. The RCM layer(s) could be placed from a barge in the offshore areas and from the shoreline using land-based equipment in the nearshore areas. RCMs initially float and then sink upon saturation with water. Sand bags may be used to accelerate RCM placement onto the sediment surface.

From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to offset cap thickness and maintain the existing nearshore area profile (i.e., 6 inches of sediment removal). Sediment removal would likely be conducted using mechanical removal equipment either from a barge or from the shoreline. Sand would likely be placed using barge-mounted mechanical clamshell equipment. To the extent practicable, nearshore erosion protection would be placed with land-based equipment. The removed sediment would be dewatered and disposed of as described in Section 6.3.4.7.3.

As detailed in Appendix E, the estimated area of the RCM caps would be 215,000 sf, and the estimated volume of material dredged would be 600 cy. Based on an assumed RCM reactive cap placement rate of 10,000 square feet per day (including reactive material and sand) and dredging rate of 400 cy per day, RCM capping would require approximately 5 weeks to implement.

6.3.2.4 Alternative 2 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with a permeable cap to prevent direct contact with affected soil. However, soil caps require ongoing monitoring and maintenance to ensure cap effectiveness. Institutional controls to prevent intentional disturbance of soil caps covering contaminated soils would be required and would include reference to the site OMMP.

The design of the cap would depend on habitat considerations and may vary across the Site. For the purpose of developing cost estimates, the FS assumes that the cap would be constructed prior to development, and used the following assumptions:

- The habitat area (see Section 6.2.2) would be re-contoured to allow for development of functional wetland and riparian habitat. Soil would be excavated to an average depth of 3 feet across this area, resulting in overexcavation and disposal of up to 14,800 cy of material.
- A marker fabric layer would be placed across the entire Site to delineate existing soil from future clean fill/cap materials.
- A 3-foot-thick permeable soil cap would be placed over the entire Site where soil cleanup numbers are exceeded, excluding the habitat area, as shown on Figure 6-1. Whether a cap would be necessary for the habitat area would be determined as part of remedial design and inconjunction with the design for habitat and wetland mitigation.

Construction of the upland cap is estimated to take approximately 3 months.

6.3.2.5 Alternative 2 Institutional Controls

Alternative 2 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR. This remedy leaves all PTW, and contaminated soil and sediment in place. As a result, for Alternative 2 to remain protective, the use of institutional controls (and monitoring) are essential to ensure that remedial technologies remain intact, are functioning as intended, and are protective, in perpetuity. Institutional controls are needed to prevent: 1) exposure to media of concern or 2) remedy failure due to "controllable" events. If a remedial technology could fail due to events that are "uncontrollable" such as earthquakes, the remedy must be engineered properly to prevent remedy failure.

Remedies that leave most, if not all, contamination in place, are best protected by the use of layers of institutional controls, i.e., more than one type of institutional control for each type of remedial technology used, for exposure pathways and/or media of concern. For Alternative 2, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions regarding disturbance of caps and subsurface soils, and access to uplands.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading.
- Surface water – no fishing, no swimming, and no wading.

As noted in the Section 6.2.5, certain institutional controls are enforceable and others are not. Most institutional controls focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to sediment and/or surface water are not enforceable either because there is no legal authority to do so or because there is insufficient oversight.

6.3.3 *Alternative 3 –Targeted PTW Solidification (RR and MC-1 DNAPL Areas)*

Alternative 3 includes the same use of upland and sediment capping, monitoring, and institutional controls as Alternative 2, but also involves treatment of targeted areas of upland PTWs and additional treatment measures to further address contaminant migration near the shoreline. Alternative 3 includes the following components:

- *In situ* solidification of deep PTWs in the RR DNAPL Area and MC DNAPL Area to remove source material contributing to comtamination of the Deep Aquifer;
- DNAPL collection trenches east of the habitat area, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A PRB east of the habitat area (downgradient of the DNAPL collection trenches) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

A description of the remedial actions that would be taken in this alternative is provided below and summarized in Table 6-1. A schematic showing the layout of alternative components is provided on Figure 6-4. Subsurface components of this alternative are shown along representative cross sections on Figures 6-5 and 6-6. Remedial area and material volume estimates are summarized in Table 6-2.

6.3.3.1 Alternative 3 Solidification of Deep Upland PTWs

To reduce the volume of the Deep Aquifer contaminant plume, this alternative targets treatment of PTWs with the greatest potential effect on the Deep Aquifer: 1) PTWs located close to or in the Deep Aquifer; and 2) PTWs in the eastern portion of the Site, where downward groundwater gradients transport contamination from the Shallow Aquifer to the Deep Aquifer.

As described in Section 4, PTWs may be present in the transition zone between the Shallow Aquifer and the Deep Aquifer in the RR DNAPL Area. DNAPL in the eastern portion of the MC DNAPL Area (near MC-1) is within approximately 2 feet of the Deep Aquifer. To determine the area on the eastern portion of the Site (where downward gradients and therefore the potential for contaminant migration into the Deep Aquifer are greatest) that would provide the most efficient reduction in Deep Aquifer plume volume, the FS groundwater model was used to estimate the reduction in plume volume for different scenarios targeting progressively larger PTW areas on the eastern portion of the Site. Modeling assumptions are described in Appendix A and the areas addressed by each scenario are shown on Figure A-2. Three scenarios were modeled, as follows:

- Solidification of the RR DNAPL Area (Area 1 on Figure A-2), which includes the easternmost[6] and deepest (34 feet, at the top of the Deep Aquifer, at boring BH-30C) DNAPL occurrences;
- Solidification of the RR DNAPL Area and PTWs directly west of the RR DNAPL Area, including at borings MC-20, MC-23, and HC-5 (see Figure 4-3, and Areas 1 and 2 on Figure A-2); and
- Solidification of the RR DNAPL Area, PTWs directly west of the RR DNAPL Area, and additional PTWs located around borings BH-9, MC-18, and HC-4 (Areas 1, 2, and 3 on Figure A-2);

Additional scenarios involving PTW treatment west of Areas 1, 2 and 3 on Figure A-2 were not modeled because hydraulic gradients in the Deep Aquifer are primarily horizontal in the center of the Site and have an upward component near the shoreline (see Section 3.3).

The FS groundwater model predicts that removing or solidifying the RR DNAPL Area provides a significant reduction in plume volume (34 percent). Additional removal or solidification of PTWs further west results in additional reduction in groundwater contaminant plume volume, but the reduction is not proportional to the amount of soil treated. Including Areas 2 and 3 involves solidifying more than double and triple the amount of soil when compared to solidification of Area 1 but is predicted to reduce the plume volume by only an additional 8 and 14 percent, respectively. The estimated volume of soil treated and the model-predicted percent reduction in contaminant plume volume are provided in Table A-5.

In situ solidification was selected as the treatment method because it would be easier to implement than other methods but provides a similar level of effectiveness. The FS groundwater model (see Appendix A) was used to compare the effect, after 100 years, of implementing three potential treatment methods on plume volume: 1) excavation, off-site disposal, and replacement with clean imported fill; 2) excavation, on-site treatment, and backfill with treated soil; and 3) *in situ* solidification. The model predicted that these three treatment methods, when applied to the RR DNAPL Area, would result in a similar level of plume reduction (29 to 34 percent by volume: see Table A-4). Excavation of PTWs in this area would be difficult and expensive because of the presence of PTWs at great depth (34 feet) in the top of the Deep Aquifer, which would require substantial shoring and construction dewatering to access. Therefore, *in situ* solidification was

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[6] DNAPL is also located further east in the Solid Materials Loading Area but DNAPL in that area has limited impact on groundwater quality (see Section 4.4.2.4) and is assumed to be a negligible contributor to contamination in the Deep Aquifer.

selected as the treatment method. The extent of solidification and assumed construction methods are discussed below.

6.3.3.1.1 Area and Volume of Solidified Soils

In this alternative, PTWs in the RR DNAPL Area and the eastern portion of the MC DNAPL Area (polygon MC-1 on Figure 4-6) would be solidified. Soil located between or overlying layers of PTWs would also be solidified. For the purposes of this FS, it is assumed that solidification would include soil to a depth of 2 feet below the estimated bottom of PTWs. This would provide a buffer between solidified contaminated soil, which remains a potential contaminant source, and the surrounding aquifer. Figure 6-4 depicts the area of soil to be solidified and Figure 6-5 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification includes approximately 0.4 acre to a maximum depth of 36 feet, and approximately 17,500 cy.

6.3.3.1.2 Soil Solidification Methods

Soils would be solidified *in situ* using large-diameter augers. The augers would include a mixing shaft to add amendments such as cement, soda ash, and/or bentonite to the soil. As the auger advances through the soil, cement grout (and any additives) would be pumped through the mixing shaft and out jets at the bottom of the auger. Augering would be performed in an overlapping pattern to amend the upland soils. Actual amendments and the amendment columns would be determined during remedial design. Testing would be performed to confirm that mixing is complete and that permeability and strength requirements are achieved.

In 2004, solidification was used at the adjacent former J.H. Baxter & Company site to remediate soil containing some of the same COCs (creosote-contaminated soil). Solidification was performed with 8.5-foot-diameter augers and soils were amended with 25 percent cement and 1 percent bentonite by dry weight. Solidification of Deeper Alluvium soils may require a smaller diameter auger because of the greater depth and denser materials.

Depending on the concentration of amendments added, it is estimated that the soil volume would increase between roughly 10 and 30 percent as a result of solidification (Riser-Roberts 1998.) For the purposes of this FS, it is assumed that the soil volume would increase by approximately 20 percent; this would result in a maximum increase in grade of approximately 7 feet (for solidification to a maximum depth of 36 feet). Because it is anticipated that future development would raise the overall grade of the Site (see Section 6.2.1), no removal or disposal of excess soil is assumed for the FS.

Based on a maximum estimated soil stabilization rate of 600 cy per day[7], solidification of this area is estimated to take approximately 2 months. Additional time would be required for mobilization, Site setup, and Site restoration. It is estimated that construction of this remedy component would take 4 months.

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[7] This solidification rate is based on the average production rate at the Columbus, GA Site (EPA 1999). Estimated duration assumes solidification work would be conducted 5 days per week during normal working hours.

6.3.3.2 Alternative 3 DNAPL Collection Trenches

Collection trenches would be installed to intercept mobile DNAPL. Although DNAPL attributes at the Site indicate a low-migration potential, either because it is stratigraphically trapped by low-permeability layers in the Shallow Alluvium or because it is present below its residual saturation, the complexity of Site geology makes it difficult to fully assess potential migration pathways. DNAPL collection trenches would provide a means of removing DNAPL that has the potential to migrate from the uplands into lake sediments. However, because of its low migration potential, it is expected that only a small portion of Site DNAPL would be mobile enough to be captured by the trenches.

DNAPL collection trenches have been implemented at similar sites, such as the American Creosote (EPA 1993b), Garland Creosoting (EPA 2006), and Madisonville Creosote Works (EPA 2012) sites. DNAPL collection trenches have been constructed of gravel, organoclay, or a combination of the two. Gravel-filled trenches contain a sump to which DNAPL drains. The gravel collection trench would facilitate collection of DNAPL, which would be removed and treated. An organoclay-filled trench would adsorb and immobilize the DNAPL in place, also removing sheen and a portion of the dissolved phase. A trench can also combine both the gravel-sump and an organoclay-containing RCM along the downgradient wall. The advantage of this combination is that in addition to gravity settling of the bulk DNAPL, any sheen or DNAPL particles that are too small to settle before crossing the trench would be adsorbed to the organoclay RCM. Both the organoclay-filled trench and the combination trench would help improve performance of the groundwater treatment wall (see Section 6.3.3.3).

DNAPL collection construction methods would be analyzed and specific design details (e.g., dimensions and materials) would be determined during remedial design. For the purposes of this FS, DNAPL would be collected under this alternative using gravel-collection trenches and an organoclay RCM would be placed in trench sections that are directly adjacent to the permeable groundwater treatment wall. DNAPL collection trenches would be constructed as follows:

- Five 2-foot-wide trenches would be constructed along approximately 500 feet of shoreline where DNAPL has been identified. Trench alignments are shown on Figure 6-4. Trenches would be placed as close as practicable to the shoreline but outside the future shoreline habitat area (see Section 6.2.2) to facilitate access for O&M. One trench would be constructed near the mouth of the former May Creek Channel, and four trenches would be constructed east of the habitat area, adjacent to the Quendall Pond Uplands area. Multiple trenches are assumed for this area to target different depths along the edge of the habitat area and to reduce the lateral distance, and required sloping, of collection piping at the base of each trench. Because the soils in this area are heterogeneous, an impermeable liner would be placed at the bottom of the trench to prevent DNAPL entering the trench from migrating into adjoining permeable soil layers.
- Trenches would be excavated using an excavator and temporary sheet piling for shoring. Trenches would be keyed into the low-permeability soil layers beneath the deepest DNAPL occurrence along each alignment, to the extent

that low permeability layers are present and properly aligned to successfully key in trenches that prevent contamination from migrating under a wall or trench. An impermeable, chemically resistant high-density polyethylene (HDPE) liner and a 4-inch-diameter perforated HDPE collection pipe would be placed at the trench base. The base of each trench would be sloped to an approximately 3-foot-deep, 12-inch-diameter stainless steel collection sump.

- A 4-inch-diameter HDPE riser pipe would be installed in each sump to an access manhole at the ground surface.
- A 4-inch-diameter HDPE cleanout pipe would be installed at the end of the collection pipe opposite the sump (or at both ends if the sump is centrally located) for maintenance purposes, with an access manhole at the ground surface.
- An RCM would be used to line the downgradient trench wall adjacent to a PRB.

The trench would be backfilled with pea gravel and topped with an impermeable cap. Soil excavated during the trench installation would be stockpiled, characterized, and disposed of accordingly. For the purposes of this FS, PTW soil is assumed to be designated as a characteristic hazardous waste and/or state-only dangerous waste, and would be disposed of as a hazardous waste at a RCRA Subtitle C landfill. An estimated 926 cy of contaminated soil, including 167 cy of PTW soil, would be removed during trench installation.

Temporary dewatering from inside the trench would be performed to facilitate construction. In some areas, dewatering may also be required to depressurize the Deep Aquifer. The maximum estimated flow rate to facilitate construction of a 25-foot-deep, 100-foot-long trench along the shoreline is 50 gallons per minute (gpm; see Appendix A, Table A-10). Although additional testing and analysis would be required prior to construction design, it is assumed that water generated during construction would be treated and discharged to the sanitary sewer.

Construction of DNAPL collection trenches is estimated to take approximately 3 months.

DNAPL recovery is assumed to be performed by periodically pumping sumps manually rather than by using automated pumps. Based on the pilot test results, the initial recovery rate is estimated to be less than 500 gallons per year (see calculation in Appendix E). Based on the performance of DNAPL collection trenches at other sites, the rate of recovery is likely to decline over time.

Based on the chemical characteristics of DNAPL collected during previous pilot testing, it is assumed that collected DNAPL would be a characteristic hazardous waste given the anticipated concentrations of benzene, and also a Washington State persistent dangerous waste given the anticipated concentrations of PAHs. Collected DNAPL would be placed in 55-gallon drums and temporarily stored on the Site within a secured area with secondary containment. For disposal, DNAPL would be shipped to a hazardous waste treatment facility for incineration.

6.3.3.3 Alternative 3 Permeable Reactive Barrier

A subsurface PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington.

The PRB configuration, treatment media, and construction methods would be determined as part of remedial design, which would likely need to include treatability testing and detailed hydraulic modeling. For the purposes of this FS, a conceptual design based on preliminary modeling and implementation at other sites was developed as described below.

PRB Configuration. PRBs are typically constructed in one of three general configurations:

- A continuous vertical zone "wall" of permeable treatment media. This configuration is simple to construct but uses a large volume of treatment media, and replacement or maintenance of media over the full length of the wall is costly;
- A funnel and gate, in which impermeable wall sections ("funnels") are used to divert groundwater through 'gates' filled with permeable treatment media. This configuration allows maintenance to be focused on a subset of the full-wall alignment, but requires detailed analysis during remedial design to control mounding, ensure hydraulic capture, and optimize the performance of the adjacent sediment caps; and
- A reactor system, in which groundwater is collected in a gravel trench behind an impermeable wall, directed through underground reactor vessels filled with permeable treatment media, and discharged on the other side. This system allows the most flexibility in replacing media or using different media in sequence; however, it is the most complicated in controlling hydraulics and would require the most frequent maintenance.

For this FS, a funnel and gate configuration is assumed to provide an appropriate balance between design complexity and maintenance requirements. The FS groundwater model was used to identify a funnel and gate conceptual layout that would capture groundwater with significant PRG exceedances (i.e., in and near DNAPL areas) without increasing the lateral extent of the groundwater plume (see Appendix A). The conceptual layout is shown on Figure 6-4. The FS groundwater model predicted a maximum increase in hydraulic head of 1.5 feet behind the impermeable funnel sections. Additional modeling details, including the predicted lateral and vertical extent of the plume before and after funnel and gate installation, are provided in Appendix A.

Treatment Media. The PRB would be designed to remove hydrocarbons, including benzene, naphthalene, and benzo(a)pyrene, from groundwater. Potential treatment media for these COCs include GAC, organoclay, organic materials such as peat or mulch, and biostimulants such as air (via sparging) or nutrients such as calcium nitrate. For this FS, GAC was assumed as the treatment media because it is conventionally used in groundwater treatment for COCs associated with coal tar and creosote[8] and has been successfully applied in full scale PRBs (Niederbacher 2000; Schad et al. 2000).

Location and Dimensions. The PRB would be located immediately downgradient of the DNAPL collection trenches so that the treatment media would not get saturated from free product. Similar to the DNAPL collection trenches, the treatment wall would be located just east of the habitat area to facilitate maintenance without disturbing habitat. Because groundwater velocities would be highest directly downgradient of the gates, gates would not be placed in areas upgradient of PTWs to avoid mobilizing contamination.

The treatment wall would be constructed to a depth of approximately 25 feet to intercept the majority of the Shallow Alluvium groundwater plume without extending into Deeper Alluvium. The treatment wall would likely not extend into the Deeper Alluvium for the following reasons:

- To avoid introducing potential downward migration pathways into the Deeper Alluvium for DNAPL trapped in the Shallow Alluvium;
- Construction of a PRB to depths sufficient to intercept the full vertical extent of the groundwater plume (greater than 120 feet) would be very difficult; and
- Dissolved-phase contamination in the Deeper Alluvium has a much longer flowpath for attenuation before reaching Lake Washington. Monitoring to confirm that the Deeper Alluvium plume is stable or shrinking is included in this alternative (see Section 6.3.3.9).

Construction Method. PRBs can be constructed using a variety of methods. For the purposes of this FS, the PRB is assumed to be constructed using one-pass trenching because it is a proven method of placing both permeable and impermeable materials without the need for shoring or construction dewatering.

Depending on final design analyses, offshore of the treatment gates (i.e., zones of preferential groundwater flow) may be required to ensure the long-term effectiveness of nearshore sediment caps constructed in these areas. However, the extent of nearshore sediment dredging (and backfill with clean materials) in this scenario is anticipated to be minimal.

Construction of the funnel and gate PRB is estimated to take approximately 2 months.

Maintenance Requirements. PRBs generally require minimal maintenance; typically, they only require performance monitoring. However, more substantial maintenance may be required occasionally. Because the PRB is designed to absorb contaminants passing through it, the treatment media has the potential to become saturated. Because the source of contamination is expected to remain for a long time, it is likely that at some time in the

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[8] GAC has limited effectiveness for treating arsenic. For the purposes of this FS, the PRB is assumed not to provide treatment of arsenic as the arsenic concentrations exceeding the MCL along the shoreline are primarily detected in the Deep Aquifer (see Figure 3-12), below the proposed PRB.

future, the media in the treatment gates would need to be replaced to prevent contaminant breakthrough.

The lifetime of the PRB treatment gates was estimated (see Appendix E) at approximately 30 years, based on the dimensions described above and the following assumptions:

- Groundwater velocity through a treatment gate of 1.1 ft/day, based on the maximum estimated by hydraulic modeling (see Appendix A);
- Benzene being the first COC to break through, based on its high concentration and low sorption potential relative to other COCs;
- An average benzene concentration in groundwater of 7.9 mg/L, based on the concentration detected in the Shallow Alluvium at monitoring well BH-20A, located near the northern treatment gate; and
- A safety factor of 2 (i.e., the change-out frequency was assumed to be twice the frequency required based on the parameters above) to account for uncertainty in how field performance may vary from predicted performance.

Spent GAC is assumed to require disposal as a RCRA hazardous waste based on potential benzene concentrations.

6.3.3.4 Alternative 3 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not covered with sand or reactive sediment caps (see Sections 6.3.3.5 and 6.3.3.6, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.3.5 Alternative 3 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of the PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.3.6 Alternative 3 Reactive Core Mat Cap

RCM sediment caps would be placed over sediments containing near-surface PTWs, specifically in the TD areas. Reactive caps would cover the same footprint as described for Alternative 2. As detailed in Appendix E, the estimated area of the RCM caps would be 247,000 sf, and the estimated volume of material dredged would be 1,000 cy. Based on an assumed RCM reactive cap placement rate of 10,000 square feet per day (including reactive material and sand) and dredging rate of 400 cy per day, RCM capping would require approximately 6 weeks to implement.

6.3.3.7 Alternative 3 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with a permeable engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above). Areas solidified would not reguire a cap.

6.3.3.8 Alternative 3 Institutional Controls

Alternative 3 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 3 includes *in situ* solidification, PRBs, and DNAPL collection trenches. Like Alternative 2, this remedy leaves most of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 3 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. In addition, Alternative 3 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools that comprise Alternative 2.

6.3.4 *Alternative 4 –Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)*

Alternative 4 includes the same remedial technologies as Alternative 3, but instead of treating deep upland PTWs in the RR and MC-1 DNAPL Areas to reduce the groundwater contaminant plume volume in the Deep Aquifer, Alternative 4 includes targeted removal of PTWs in the Quendall Pond (QP) and selected T-Dock (TD) DNAPL Areas. The reason for targeting the TD DNAPL Area sediments is to remove PTW present as DNAPL in shallow sediments. The QP DNAPL Area includes oil-wetted, mobile DNAPL close to the Lake Washington shoreline (QP-U DNAPL Area) and in sediments located immediately off-shore (QP-S DNAPL Area), at approximately 10 feet below the mudline. The purpose of targeting these areas is to remove the greatest mass of potentially mobile PTW in the shoreline area of the Site. In the event of a seismic event, PTW in the the QP-U DNAPL Area could migrate into Lake Washington and expand the area of PTW contamination in the nearshore area. Similarily, DNAPL in the QP-S DNAPL Area could also migrate further within the lake. Alternative 4 includes the following components:

- Excavation of PTWs in the QP-U DNAPL Area to remove source material adjacent to the lake;

- DNAPL collection trenches east of the habitat area, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A PRB east of the habitat area (downgradient of the DNAPL trenches) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in other aquatic PTW areas to sorb DNAPL and control DNAPL migration;
- Removal of sediment PTW in the QP-S and TD (DA-1, DA-2 and DA-6) DNAPL Areas to eliminate most PTW in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 4 (not including upland capping which, for clarity, is shown on the Alternative 3 plan view [Figure 6-5] but not on the plan views of subsequent alternatives) are shown on Figure 6-7. Representative cross sections illustrating this alternative's subsurface components are provided on Figures 6-8 and 6-9. Each component is discussed below.

6.3.4.1 Alternative 4 Removal of Upland PTWs (QP-U DNAPL Area)

In this alternative, PTWs in the QP-U DNAPL Area would be excavated, disposed of off site, and replaced with clean imported fill. Excavation and off-site disposal was selected rather than: 1) excavation, on-site treatment, and backfill with treated soil or 2) *in situ* solidification based on the following constructability and cost considerations. This alternative also includes removal of sediments in the adjacent QP-S DNAPL Area. Removal of the two areas in tandem could allow for construction efficiencies. Additionally, for the estimated soil volume to be removed (12,700 cy), on-site treatment is not expected to be cost-effective compared to disposal based on economies of scale for mobilizing and operating on-site treatment equipment.

The extent of soil removal and assumed construction methods are discussed below.

6.3.4.1.1 Areas and Volumes of Soil to be Removed

The lateral and vertical extent of the QP-U DNAPL Area is described in Section 4.4.2.3 and includes layers of potentially mobile DNAPL of significant thickness within 100 feet of the shoreline. Removal of adjacent sediment PTWs is described in Section 6.3.4.6.

Figure 6-7 depicts the area of soil to be removed, and Figure 6-8 depicts a representative cross section of the vertical extent of soil to be removed. Approximately 0.5 acre to a maximum depth of 19 feet would be removed, resulting in removal of 15,600 cy of upland soil.

6.3.4.1.2 Soil Removal Methods

Excavation below the water table can be performed “in the dry” or “in the wet”. Wet excavation, similar to dredging, leaves behind residual contamination, as discussed in Section 5.3.4.5, leading to longer timeframes for groundwater restoration compared to dredging in the “dry”. However, dry excavation can require substantial dewatering and depressurization of the Deep Aquifer, which raises cost and can mobilize contamination below the excavation prism before it is removed.

For Alternative 4, contaminated residuals resulting from wet excavation would be left behind and managed through backfilling. However, to the extent that dewatering can be conducted in a cost-efficient manner, dry excavation is still preferred for a number of reasons, including:

- More efficient removal of material. For variable depth excavations, sidewall slopes would likely be much less steep (resulting in additional volume removed) under saturated conditions;
- Less handling and processing of excavated material to remove water;
- Easier field verification of excavation extent and performance; and
- Fewer contaminated residuals.

To excavate material in this Site area, both excavation methods would require temporary shoring to achieve target depths and prevent sidewall sloughing. Shoring (discussed in Section 6.3.4.1.3) would be provided with temporary sheet piles surrounding the excavation area. In addition, an excavation that is accompanied by dewatering may require Deep Aquifer depressurization to maintain excavation stability. The Quendall Pond area would requires dewatering and depressurization whether excavation is performed wet or dry based on requirements for tieback installation as part of the shoring design (see Appendix F). Dewatering assumptions and shoring construction are discussed in Section 6.3.4.1.4.

After soils are removed from the cell, clean imported fill would be used to restore the original Site grade. Only for the purposes of estimating construction costs for the FS, the areas excavated in the wet would be backfilled with a material such as 1-inch rock that can be adequately compacted under saturated conditions. Backfill material will be determined during remedial design in consultation with regulatory agencies with oversight for the remedial action, ESA, Magnuson-Stevens Act, etc. Fill would be placed in lifts and compacted. After the grade is restored, the sheet pile wall segments would be removed.

Based on a maximum estimated rate of 400 cy[9] per day for excavation and backfilling, removal of this area is estimated to take approximately 2 months. Additional time would be required for mobilization, Site setup, shoring and dewatering installation, and Site restoration. It is estimated that construction of this remedy component would take 8 months.

6.3.4.1.3 Shoring

Impermeable shoring walls would be installed around the excavation perimeter to prevent sidewall sloughing and to reduce the construction dewatering rate. Without shoring, unstable sidewall sloughing would require removal and disposal of contaminated material outside the targeted excavation area. In particular, shoring walls along the shoreline would be required to separate removal activities from Lake Washington.

Process options for impermeable shoring walls include sheet pile walls, secant pile walls, and cutterhead soil mixing walls. Each of these options could potentially be implemented at the Site. For the purposes of this FS, temporary sheet pile walls (which could be removed and reused) were identified as the likely least costly option. Conceptual design criteria for a sheet pile wall for a 19-foot-deep excavation include one row of tieback anchors and a minimum embedment depth of approximately 35 feet. Preliminary shoring design considerations are described in Appendix F. The sheet pile shoring wall perimeter is shown on Figure 6-7, and the estimated embedment depth is shown on Figure 6-8.

6.3.4.1.4 Construction Dewatering and Water Treatment

For the purposes of this FS, it is assumed that Deep Aquifer depressurization is necessary to perform excavation whether done wet or dry. To excavate PTWs in the vicinity of Quendall Pond, depressurization flow rates of 590 gpm are estimated to be needed to excavate in the dry, while wet excavation could be accomplished with a depressurization rate of 207 gpm (Cell 7: see Appendix A, Tables A-9 and A-10). For the QP-U DNAPL area addressed by this alternative, wet excavation can be accomplished with a depressurization rate of 120 gpm (see Table A-9). Additional testing during design would be needed to ensure that dewatering and groundwater modeling assumptions are accurate.

Groundwater removed during dewatering activities would be treated and discharged. The level of treatment would depend on where treated water would be discharged, which could be one of the following:

- To the City of Renton sanitary sewer system, under a City of Renton and/or King County Metro sewer discharge permit. Discharged water would be treated by the King County sewer treatment plant or pretreated at the Site per the sewer discharge conditions; or
- To Lake Washington after treatment. The substantive requirements of a temporary NPDES permit would need to be defined with Ecology and could potentially allow for a mixing zone.

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[9] This type of removal and fill was performed at the former Barbee Mill site in 2006 (Aspect 2006). The Barbee Mill average removal and fill rate was used in this study because it accounts for area-specific hauling and working hour constraints.

For the estimated maximum flow rate under this alternative, discharge to the City of Renton sanitary sewer system is anticipated to be the most cost-effective option. An on-site treatment system would be required to reduce COC concentrations to appropriate discharge limits.

The treatment system is assumed to include the following major components:

- Decant tank to remove DNAPL;
- Equalization/sedimentation tank to provide storage capacity and remove solids;
- Chemical precipitation mixing tank and clarifier to remove iron and manganese;
- Air stripper to remove VOCs, including benzene;
- Vapor-phase GAC adsorption units, to treat air-stripper offgas;
- Liquid-phase GAC adsorption units, to remove PAHs; and
- Sand filters upstream of the liquid-phase GAC adsorption units, to reduce fouling.

Based on the maximum concentration of arsenic detected in the QP-U DNAPL Area (51 µg/L in BH-20B) and the typical King Country Metro discharge limit for arsenic (1 mg/L), no treatment to address arsenic is assumed necessary.

6.3.4.1.5 Management of Removal Soil

Excavated soil would be segregated based on its potential waste designation. In this area of the Site, RCRA-listed wastes are not expected to be encountered; however, PTW soil may be designated as a characteristic RCRA waste based on the presence of benzene or a state-only dangerous waste based on the presence of PAHs. Segregated soil would be stockpiled and tested. Free liquids draining from soil stockpiles would be collected and treated using the construction dewatering treatment system (see Section 6.3.4.1.4). After testing, soil would be loaded into trucks and transported to an appropriate facility as follows:

- Soil containing benzene less than 5 mg/L by TCLP extraction and less than 1 percent by weight PAHs would be transported to a Subtitle D landfill for disposal.
- Soil exceeding 5 mg/L benzene via TCLP extraction or 1 percent by weight PAHs would be transported to a RCRA Subtitle C landfill for disposal.

6.3.4.2 Alternative 4 DNAPL Collection Trenches

Collection trenches would be installed outside the eastern boundary of the habitat area to intercept potentially mobile DNAPL. DNAPL collection trenches would provide a means of both monitoring and removing DNAPL that has the potential to migrate from the uplands toward the Habitat Area and lake sediments. This alternative assumes DNAPL collection trenches would be constructed as described in Alternative 3 (see Section 6.3.3.2 above).

6.3.4.3 Alternative 4 Permeable Reactive Barrier

A PRB would be installed outside the eastern boundary of the habitat area in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward the Habitat Area and Lake Washington. The treatment wall would assist natural attenuation to protect potential Habitat Area, sediment and surface water receptors and enhance recovery of the contaminated groundwater, sediments and porewater. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3 above), except that the northern treatment gate would be moved upgradient of the soil excavation and backfill area. Placing the gate in this location would reduce groundwater flow velocities through PTWs remaining near the shoreline.

6.3.4.4 Alternative 4 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not covered with sand or reactive sediment caps (see 6.3.4.5 and 6.3.4.6, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.4.5 Alternative 4 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of the PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.4.6 Alternative 4 Reactive Cap

The reactive capping approach for Alternative 4 is the same as described in Section 6.3.3.6 for Alternative 3, except the extent of reactive capping is reduced in Alternative 4. Alternative 4 includes placing reactive caps over aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8. All reactive caps would be RCMs (Configuration One as described in Section 6.3.2.3). The remaining aquatic DNAPL areas would be dredged as described below in Section 6.3.4.7. As detailed in Appendix E, the estimated area of reactive cap would be 86,000 sf, and the estimated volume of material dredged would be 600 cy. Based on an assumed reactive cap placement rate of 10,000 sf per day (including reactive material and sand) and dredging rate of 400 cy per day, reactive capping would require approximately 2 weeks to implement.

6.3.4.7 Alternative 4 Sediment Removal

The areas proposed for dredging in Alternative 4 include the TD DNAPL Area (DA-1 and DA-2) and the QP-S DNAPL Area (DA-6). These TD areas contain near-surface DNAPL deposits that may be potentially disturbed by boating activities such as anchoring, erosional forces from natural events such as wind or following a large seismic event. As described in Section 4.4.1.6, the TD DNAPL Area is of particular concern due to the presence of DNAPL shallow sediments. The purpose of targeting the QP-S DNAPL area is to remove DNAPL that is of particular concern due to its effect on groundwater quality beneath the lake, thickness, and potentially mobility.

The effectiveness of dredging these areas may be limited by short-term impacts during dredging (i.e., resuspension of sediments; release of particles contaminated with COCs, sheens to water; and COC volatilization to air) and by residual COCs remaining after dredging (USACE 2008 and Bridges et al. 2010). The dredge areas contain DNAPL, which increases the potential for water quality impacts during dredging. These effects may be reduced by use of experienced operators, engineering controls (e.g., sheet piles, silt curtains, booms), BMPs (e.g., production rates, bucket control, etc.) and/or by equipment selection. In addition, all dredging work would occur prior to capping work to reduce the potential for recontamination of capping areas that are adjacent to dredging areas. The extent and methods of dredging are described below.

6.3.4.7.1 Areas and Volumes of Sediment to be Removed

Figure 6-7 depicts the area of sediment to be removed, and Figure 6-9 depicts a representative cross section of the vertical extent of sediment to be removed. Removal depths correspond with observed depths of DNAPL. These dredge areas assume 2 horizontal to 1 vertical (2H: 1V) side-slopes to reduce sloughing and failure of adjacent sediments. A shallower slope (3H: 1 V) may be required in some areas where sediments are relatively soft or in deeper dredge areas. An overdredge allowance of 1-foot deeper than the target dredge depth was included in volume calculations. Calculations, including depths and areas of individual dredge areas and associated sediment core reference locations, are provided in Appendix E.

The estimated extent of sediment removal includes approximately 12,200 cy of offshore sediment and 11,000 cy of nearshore sediment for a total of 23,200 cy not including sediment removed for offsetting the cap thickness.

6.3.4.7.2 Sediment Removal Methods

Hydraulic Dredging. Offshore PTWs in the TD DNAPL Area (DA-1 and DA-2) would be removed by hydraulic dredging. DA-1 and DA-2 have relatively shallow target dredge depths which would allow use of hydraulic dredges designed for environmental dredging (e.g., SedVac® by Terra Contracting or the VicVac™ by Brennan). These have the potential for greater control of resuspension and releases than larger navigational hydraulic dredges (USACE 2008). In addition to using environmental dredging equipment, the potential short-term impacts may be further reduced by containing dredge areas within oil-sorbent booms and/or silt curtains. Because hydraulic dredges are not effective at handling debris, relic offshore structures would be removed prior to dredging. It is estimated that approximately three dolphin buoys of five piles each would need to be pulled to allow dredging in DA-2. A portion of DA-2 overlaps the existing DNR Dry Dock Cap and a small portion of the remaining concrete ballast and wood hulls of the former dry docks (Figure 6-7). Because previous attempts to remove the hulls proved challenging, DNR left the structures in place and placed approximately 6-inches of clean sand over the structures. Portions of this cap would be dredged while dredging underlying PTWs. A small portion of DA-2 that contains the dry dock hulls would remain in place. The dredged material would be conveyed directly to an upland staging area in a pipeline.

Mechanical Dredging. Nearshore PTWs in the QP-S DNAPL Area (DA-6) would be removed by mechanical dredging. A temporary sheet pile enclosure would be installed around DA-6 to isolate the dredging activities from the lake and to support removal of sediments to greater than 9 feet bss. If there is substantial debris located within the footprint of the sheet pile enclosure, then this debris would require removal prior to installation of sheet pile. Mechanical dredging equipment may consist of a crane-mounted bucket or an articulated bucket (barge-mounted excavator). In areas free from debris, an environmental bucket may be used to minimize sediment resuspension during dredging operations. Where debris is present, a clamshell or conventional bucket would be required. For environmental dredging, bucket sizes are typically within the range of 3 to 10 cy (USACE 2008). Debris located within the dredge area/sheet pile wall would be removed during dredging operations, segregated, stockpiled, and disposed of off site. Dredged material would be placed into an enclosed barge and transported to an offloading area adjacent to the shoreline for transfer to an upland staging area.

The type and specifications of hydraulic and mechanical dredging equipment, as well as the extent of the use of hydraulic and mechanical dredging techniques, and specification of dredging equipment and dredging practices and BMPs as required by EPA would be determined during design or bidding, based on the detailed dredge design. Real-time positioning systems would be used on the dredges to accurately control position, monitor inventory, and track dredging progress in real-time.

Based on an assumed sheet pile installation rate of 20 linear feet (lf) per day, sheet pile removal rate of 30 lf per day, dredging rate of 400 cy per day and a backfilling rate of 500 cy/day, sediment removal would require approximately 29 weeks to implement.

6.3.4.7.3 Management of Removed Sediment

Excavated and dredged materials including debris would be shipped off site for disposal at a permitted landfill as described in Section 6.2.3. Given the high moisture content of sediments, on-site dewatering would be conducted to meet the transportation and disposal requirements (i.e., no free water) and to reduce disposal mass. For mechanical dredging, free liquid would be decanted from the barge prior to offloading the sediments to the upland staging area. Dewatering of the mechanically dredged sediments may consist of gravity dewatering followed by addition of a solidification agent (e.g., cement products, lime, or diatomaceous earth). Dewatering of the hydraulically dredged materials would require additional processes such as vacuum boxes due to the higher water content. An upland staging area would be located on a portion of the upland area of the Site and would be used for sediment dewatering prior to loading into trucks for off-site transport and disposal.

Supernatant/decant water from dewatering would be treated using a temporary on-site water treatment facility. For this FS, it is assumed that discharge would occur to Lake Washington. For costing purposes, treatment is assumed to consist of storage tanks, filtration, and GAC prior to discharge to the lake.

Following verification that dredge depths have been met, residuals management and backfilling would be completed. Residuals generated by dredging would be managed using a post-dredge residuals cover. A reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed in the dredged areas to address anticipated DNAPL and sediment residuals based on post-dredge sediment sampling. Following placement of the residuals cover, these areas would be backfilled with sand. For the cost estimate, it is assumed the dredge areas are backfilled to the existing grade. In offshore dredge areas, the need to backfill to existing grade would be further evaluated in design. Backfill may be placed to an elevation below existing grade in offshore areas.Residuals cover and backfill material may be placed using a crane-mounted clamshell bucket or using the mechanical dredging equipment (following decontamination).

6.3.4.7.4 Sediment Removal Sheet Pile Enclosure

To provide sediment resuspension control, a temporary sheet pile enclosure would be constructed prior to nearshore sediment removal. The enclosure wall alignment is shown on Figure 6-7. The wall would be approximately 700 feet long. In addition to resuspension control, the wall would also serve as excavation support along areas where removal depths are relatively deep. The wall would tie into the shoreline at both ends and would isolate the sediment removal area from the rest of the lake. Groundwater seepage could potentially occur underneath the structure if a gradient existed; however, gradients are expected to be small and therefore seepage is not considered a concern. The contractor would be required to manage the water level within the enclosure to keep water level differentials small. Water level management would limit seepage and would also limit the hydrostatic load on the sheet pile wall to allow for an economical sheet pile design. To further reduce the potential for seepage, the sheet pile interlocks would be sealed. During design, a sealant would be selected that is chemically compatible with the contaminants anticipated within the enclosure.

Based on preliminary calculations and assuming small water level differentials, a cantilevered wall constructed using regular Z-type sheet pile sections would be feasible. The wall would be designed to withstand a combination of loads, including wave load, wind load, hydrostatic load due to water level differential, lateral earth pressures, and barge impact from barges operating inside the enclosure. Based on the preliminary calculations, an AZ17 sheet pile section distributed in the United States by Skyline Steel (or similar section by another vendor with the same section modulus) would be adequate to withstand stresses within the sheet piles and limit deflections. The sheet piles would need to be embedded deep enough into the subsurface soils to provide adequate stability. A minimum embedment into the underlying deeper alluvium of 10 feet is recommended. Based on the preliminary calculations, the sheet piles would need to be approximately 50 feet long. The sizing of the sheet piles would be refined during design. Design optimization may result in the use of more than one sheet pile size and length along the wall alignment.

Due to the relatively dense nature of the deeper alluvium, an impact hammer would be needed to drive the sheet piles into the deeper soil deposits. Pile driving using an impact hammer generates significant noise (e.g., more than using a vibratory hammer) both above and underwater, which potentially may disturb nearby residences, fish and wildlife.

Some water quality impacts are anticipated to occur due to sediment resuspension during impact driving. Water quality would be monitored during enclosure construction, and modifications to the sheet pile installation and BMPs would be made as necessary to reduce water quality impacts. It is anticipated that a barge-mounted crane would be required for enclosure installation.

After dredging, backfilling, and allowing adequate settling time for resuspended sediments within the enclosure, the enclosure wall would be removed. For sheet pile removal, a vibratory hammer is expected to be adequate.

6.3.4.8 Alternative 4 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with a permeable engineered cap to prevent direct contact with affected soil. Excavated areas would not reguire a cap.

6.3.4.9 Alternative 4 Institutional Controls

Alternative 4 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 4 includes upland excavation, dredging, PRBs, and DNAPL collection trenches. This remedy leaves most of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 4 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been excavated are not expected to require a soil cap.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. In addition, Alternative 4 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools that comprise Alternative 2.

6.3.5 *Alternative 4a –Targeted PTW Solidification (RR, MC-1, and QP-U DNAPL Areas) and Removal (TD DNAPL Area)*

Alternative 4a incorporates the same upland remedial technologies as Alternative 3 to solidify deep DNAPL in the RR and MC-1 DNAPL Areas to treat groundwater and restore a portion of the Deep Aquifer. Alternative 4a adds solidification of the QP-U DNAPL Area, to target potentially mobile DNAPL located adjacent to Lake Washington. In the event of a semsic event PTW in the the QP-U Area could migrate into Lake Washington and expand the area of PTW contamination.

Alternative 4a includes the same offshore remedies as Alternative 4, except that instead of dredging shallow sediments in the QP-S DNAPL area, those sediments would be addressed with an RCM reactive cap, identical to Alternative 2.

Alternative 4a includes the following components:

- *In situ* solidification of deep PTWs in the RR DNAPL Area and MC DNAPL Area to remove source material contributing to comtamination of the Deep Aquifer, and of PTWs in the QP-U DNAPL Area to remove source material adjacent to the lake;
- DNAPL collection trenches east of the habitat area, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A PRB east of the habitat area (downgradient of the DNAPL collection trenches) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in other sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Removal of sediment PTW in the TD (DA-1, DA-2 and DA-6) DNAPL Area to eliminate shallow PTW in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 4a are shown on Figure 6-10. Subsurface components of this alternative are illustrated along representative cross sections on Figures 6-11 and 6-12. Each remedy component is discussed below.

6.3.5.1 Alternative 4a Targeted Solidification of Upland PTWs

In this alternative, deep PTWs would be solidified as described under Alternative 3 (see Section 6.3.3.1). In addition, PTWs in the QP-U DNAPL Area would also be solidified.

Figure 6-10 depicts the soil area to be solidified, and Figure 6-11 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification is approximately 0.9 acres for a total volume of approximately 38,000 cy. Soils would be solidified *in situ* using large-diameter augers as described in Alternative 3 (see Section 6.3.3.1).

Based on a maximum estimated soil solidification rate of 600 cy per day, solidification of this area is estimated to take approximately 3 months. Additional time would be required for mobilization, Site setup, and demobilization. It is estimated that construction of this remedy component would take 6 months.

6.3.5.2 Alternative 4a DNAPL Collection Trenches

Collection trenches would be installed outside the eastern boundary of the habitat area to intercept potentially mobile DNAPL. DNAPL collection trenches would provide a means of both monitoring and removing DNAPL that has the potential to migrate from the uplands toward the Habitat Area and lake sediments. This alternative assumes DNAPL collection trenches would be constructed as described in Alternative 3 (see Section 6.3.3.2 above).

6.3.5.3 Alternative 4a Permeable Reactive Barrier

A PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of groundwater contamination toward Lake Washington. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3).

6.3.5.4 Alternative 4a ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or RCM caps (see Sections 6.3.5.4 and 6.3.5.5, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.5.5 Alternative 4a Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.5.6 Alternative 4a Reactive Core Mat Cap

RCM caps would be placed over sediments containing near-surface PTWs outside of dredged areas. The RCM caps would cover the same footprint as described for Alternative 4 (see Section 6.3.4.6), with the addition of the QP-S DNAPL Area (DA-6), and they would be constructed using the same methodologies.

6.3.5.7 Alternative 4a Sediment Removal

The extent and methods of sediment removal for Alternative 4a is the same as for Alternative 4 (see Section 6.3.4.7), and includes targeted PTWs in the offshore TD DNAPL Area (DA-1 and DA-2). As in Alternative 4, offshore areas would be dredged using hydraulic dredging methods. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade.

6.3.5.8 Alternative 4a Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above). Areas solidified would not reguire a cap.

6.3.5.9 Alternative 4a Institutional Controls

Alternative 4a utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 4a includes *in situ* solidification, dredging, PRBs, and DNAPL collection trenches. Like Alternative 2, this remedy leaves most of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 4a to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. In addition, Alternative 4a includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools that comprise Alternative 2.

6.3.6 *Alternative 5 –Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)*

Alternative 5 incorporates the same upland remedial technologies as Alternative 4a to solidify deep PTWs in the RR and MC-1 DNAPL Areas to treat groundwater and restore a portion of the Deep Aquifer, and to solidify PTWs in the QP-U DNAPL Area, to target potentially mobile DNAPL located adjacent to Lake Washington. To provide additional treatment of PTWs, it also includes includes solidification of other areas of the uplands where greater than 4 cumulative feet of PTW soils are in the top 20 feet of soil column.

The greatest cumulative thicknesses of PTW soil (greater than 4 cumulative feet) [10] have been observed in the vicinity of two historical Site features where DNAPL releases have been documented: 1) the North Sump and 2) at the former sewer outfall in the former May Creek Channel. Soils in these areas would be treated using *in situ* solidification. Alternative 5 includes the same offshore remedies as Alternative 4.

Alternative 5 includes the following components:

- *In situ* solidification of upland PTWs, including the QP-U DNAPL Area, deep PTWs in the RR and MC DNAPL Areas, and areas with PTW soil greater than 4-feet cumulative thickness in the top 20 feet of soil column to treat PTWs;
- A PRB east of the habitat area to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in other sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Removal of sediment PTW in the QP-S and TD (DA-1, DA-2 and DA-6) DNAPL Areas to eliminate most PTWs in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 5 are shown on Figure 6-13, and a representative cross section for upland components is provided on Figure 6-14. Sediment components are the same as for Alternative 4; therefore, refer to Figure 6-9 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.6.1 Alternative 5 Targeted Solidification of Upland PTWs

In this alternative, deep PTWs would be solidified as described under Alternative 3 (see Section 6.3.3.1). In addition, PTWs in the QP-U DNAPL Area and upland areas containing 4 feet or more (cumulative thickness) of PTW soil in the upper 20 feet would also be solidified.

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[10] Refer to Sheet E-12 in Appendix E and Figure 4-6 for specific areas. DNAPL depth intervals are provided in Tables G-1 and G-2 of the RI Report (Anchor QEA and Aspect 2012).

For the purposes of this FS, it is assumed that solidification outside of deep PTW areas would include soil up to a depth of 20 feet. Additional vertical delineation of shallow PTW in these areas would be performed as part of the design to determine the required solidification depth for PTWs above 20 feet.

Figure 6-13 depicts the soil area to be solidified, and Figure 6-14 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification is approximately 2.3 acres to a maximum depth of 20 feet for a total volume of approximately 79,000 cy.

Soils would be solidified *in situ* using large-diameter augers as described in Alternative 3 (see Section 6.3.3.1).

Based on a maximum estimated soil solidification rate of 600 cy per day, solidification of this area is estimated to take approximately 4 months. Additional time would be required for mobilization, Site setup, and demobilization. It is estimated that construction of this remedy component would take 7 months.

6.3.6.2 Alternative 5 Permeable Reactive Barrier

A PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of groundwater contamination toward the Habitat Area and Lake Washington. The PRB would enhance ongoing natural attenuation in the nearshore sediment area. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3).

6.3.6.3 Alternative 5 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.5.4 and 6.3.5.5, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.6.4 Alternative 5 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.6.5 Alternative 5 Reactive Core Mat Cap

Reactive sediment caps would be placed over sediments containing near-surface PTWs outside of dredged areas. The reactive caps would cover the same footprint as described for Alternative 4 (see Section 6.3.4.6), and would be constructed using the same methodologies.

6.3.6.6 Alternative 5 Sediment Removal

The extent and methods of sediment removal for Alternative 5 is the same as for Alternative 4 (see Section 6.3.4.7), and includes targeted PTWs in the offshore TD DNAPL Area (DA-1 and DA-2) and the nearshore QP-S DNAPL Area (DA-6). As in Alternative 4, offshore areas would be dredged using hydraulic dredging methods and the nearshore area would be dredged using mechanical dredging methods with sheet pile containment. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade.

6.3.6.7 Alternative 5 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with a permeable engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above). Areas solidified would not reguire a cap.

6.3.6.8 Alternative 5 Institutional Controls

Alternative 5 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 5 includes dredging, *in situ* solidification, PRBs, and DNAPL collection trenches. This remedy leaves much of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 5 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. In addition, Alternative 5 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools that comprise Alternative 2.

6.3.7 Alternative 6 –Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)

Alternative 6 incorporates the same remedy components as Alternative 4, except without DNAPL collection trenches[11]. Alternative 6 also includes targeted solidification of deep PTWs (as in Alternatives 3 and 5) to reduce groundwater plume volume and solidification of shallow PTW soil exceeding 2 feet of cumulative thickness in the top 20 feet of soil column to provide additional treatment of PTWs.

Alternative 6 includes the following components:

- *In situ* solidification of upland PTWs, including the QP-U DNAPL Area, deep PTWs in the RR and MC DNAPL Areas, and areas with PTW soil greater than 2-feet cumulative thickness in the top 20 feet of soil column to treat PTWs, which are source materials contributing to groundwater contamination;
- Excavation of upland PTWs in the QU-U DNAPL Area to eliminate PTWs adjacent to the lake;
- A PRB east of the habitat area to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in other sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Removal of sediment PTW in the QP-S and TD (DA-1, DA-2 and DA-6) DNAPL Areas to eliminate most PTWs in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 6 are shown on Figure 6-15, and upland components along a representative cross section are shown on Figure 6-16. Sediment components are the same as for Alternative 4; therefore, refer to Figure 6-9 for

[11] Areas identified for DNAPL collection trenches in Alternative 4 are targeted for solidification in Alternative 6.

illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.7.1 Alternative 6 Targeted Solidification of Upland PTWs

The purpose of Alternative 6 is to reduce the mass of PTW and to reduce the plume volume to a greater extent than Alternative 5. Alternative 6 treats PTW in soil in the upper 20 feet containing 2 feet or more cumulative thickness of DNAPL would also be solidified to provide additional treatment of PTWs.

For the purposes of this FS, it is assumed that solidification outside of deep PTW areas would include soil up to a depth of 20 feet. Additional vertical delineation of shallow PTWs in these areas would be performed as part of the design to determine the required solidification depth for PTWs above 20 feet.

Figure 6-15 depicts the soil area to be solidified, and Figure 6-16 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification includes approximately 4.2 acres to a maximum depth of 20 feet for a total volume of approximately 143,000 cy.

Soils would be solidified *in situ* using large-diameter augers as described in Alternative 3 (see Section 6.3.3.1.2). Based on a maximum estimated soil stabilization rate of 600 cy per day, solidification of this area is estimated to take approximately 7 months. Additional time would be required for mobilization, Site setup, and demobilization. It is estimated that construction of this remedy component would take 10 months.

6.3.7.2 Alternative 6 Removal of Upland PTWs (QP-U DNAPL Area)

In this alternative, PTWs in the QP-U DNAPL Area would be excavated, disposed of off site, and replaced with clean imported fill. The excavated area covers the same footprint as described for Alternative 4 and would be constructed using the same methodologies described in Section 6.3.4.1.

6.3.7.3 Alternative 6 Permeable Reactive Barrier

A PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3) except the PRB alignment would follow the eastern edge of the QP-U DNAPL Area and the northern treatment gate would be installed south of the QP-U DNAPL Area.

6.3.7.4 Alternative 6 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.6.4 and 6.3.6.5, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.7.5 Alternative 6 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.7.6 Alternative 6 RCM Cap

Reactive sediment caps would be placed over sediments containing near-surface PTWs outside of dredged areas. The reactive caps would cover the same footprint as described for Alternative 4 (see Section 6.3.4.6), and would be constructed using the same methodologies.

6.3.7.7 Alternative 6 Sediment Removal

The extent and methods of sediment removal for Alternative 6 is the same as for Alternative 4 (see Section 6.3.4.7), and includes targeted PTW areas in the offshore TD DNAPL Area (DA-1 and DA-2) and the nearshore QP-S DNAPL Area (DA-6).

6.3.7.8 Alternative 6 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with a permeable engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above). Areas solidified would not reguire a cap.

6.3.7.9 Alternative 6 Institutional Controls

Alternative 6 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 4 includes dredging, *in situ* solidification, PRBs, and DNAPL collection trenches. This remedy leaves much of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 5 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil. The areas where contaminated soils have been excavated are also not expected to require a soil cap.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. In addition, Alternative 6 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools that comprise Alternative 2.

6.3.8 *Alternative 7 –PTW Solidification (Upland) and Removal (Sediment)*

Alternative 7 involves solidification of upland PTWs and removal and on-site treatment of sediment PTWs. The primary objective of this alternative is to treat the PTW on the Site. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Alternative 7 includes the following components:

- *In situ* solidification of all upland PTWs;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 7 are shown on Figure 6-17, and representative cross sections are provided on Figures 6-18 and 6-19. Each remedy component is discussed below.

6.3.8.1 Alternative 7 Solidification of Upland PTWs

In this alternative, PTWs and overlying soil would be solidified *in situ*. With solidification, there is the potential for contaminant plume spreading from the reduction in post-solidification permeability and resultant diversion of groundwater around solidified areas. Because the altered groundwater flow path can potentially carry contaminants into previously uncontaminated areas, modeling was performed to determine the effect of solidification on the plume. Modeling predicts that the contaminant plume would shrink after solidification (see Appendix A).

The extent of soil removal and assumed construction methods are discussed below.

6.3.8.1.1 Treatment Areas and Volumes

The lateral and vertical extent of PTWs is described in Section 3.5. As described for Alternative 3 (see Section 6.3.3.1), the extent of solidification is assumed to extend approximately 2 feet below the deepest PTW in each area to provide a buffer between solidified PTWs and the surrounding aquifer.

Figure 6-17 depicts the area of solidification, and Figure 6-18 depicts a representative cross section of the vertical extent of solidification. The estimated extent of solidification includes approximately 9.7 acres to a maximum depth of 36 feet for a total volume of 241,000 cy of upland soil.

6.3.8.1.2 Solidification Methods

Based on a maximum estimated rate of 600 cy per day, solidification of this area is estimated to take approximately 14 months. Additional time would be required for mobilization, Site setup, and Site restoration. It is estimated that construction of this remedy component would take 24 months.

6.3.8.2 Alternative 7 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.7.3 and 6.3.7.4, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.8.3 Alternative 7 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2

6.3.8.4 Alternative 7 Removal of Sediment PTWs

The sediment removal approach for Alternative 7 is the same as described in Section 6.3.4.7.2 for Alternative 5, except for the extent of dredging. Alternative 7 includes dredging of the offshore (DA-1 through DA-5) and nearshore (DA-6 through DA-8) sediment PTW areas. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade. As described in Section 6.3.4.7.2, sediment removal would be performed by hydraulic dredging and nearshore sediment removal would be performed by mechanical dredging within a sheet pile enclosure. Removal depths correspond with observed depths of PTWs. An overdredge allowance of 1-ft deeper than the target dredge depth was included in volume calculations. Calculations, including depths and areas of individual dredge areas and associated sediment core reference locations, are provided in Appendix E. A representative cross section displaying the extent of sediment to be removed through the central portion of the Site is shown on Figure 6-19.

The sheet pile enclosure for Alternative 7 would be similar to the one described for Alternative 4 in Section 6.3.4.7.4. The main differences are the alignment, length of the wall, and length of the sheet piles. The enclosure wall for Alternative 7 would be 1,260 feet long. The wall alignment is shown on Figure 6-14. Based on preliminary calculations, the sheet pile sections would be AZ24. The sheet piles would need to be approximately 50 feet long to provide adequate stability.

Based on an assumed sheet pile installation rate of 20 lf per day, sheet pile removal rate of 30 lf per day, and dredging rate of 400 cy per day, Alternative 7 sediment removal and backfilling would require approximately 64 weeks to implement.

6.3.8.5 Alternative 7 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4). Areas solidified would not reguire a cap.

6.3.8.6 Alternative 7 Institutional Controls

Alternative 7 utilizes *in situ* solidification of upland PTW and dredging of sediment PTW, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 7 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6. Unlike other alternatives, the purpose of Alternative 7 is to remove all known PTW; however, contaminated soil and sediment remain in place. As a result, for Alternative 7 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of cleanup numbers. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. Cleanup numbers are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.
- Surface water – no fishing, no swimming, and no wading until cleanup numbers are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. However, most institutional controls in Alternative 7 will not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments will remediate in time.

6.3.9 *Alternative 8 – PTW Removal (Upland and Sediment)*

Alternative 8 involves removal and on-site treatment of all upland and sediment PTWs. The primary objective of this alternative is to treat all PTWs on the Site. Containment measures described in Alternative 2, except reactive sediment capping[12], are also included in this alternative to maintain protectiveness.

Alternative 8 includes the following components:

- Removal of all upland PTWs and on-site *ex situ* thermal treatment;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 8 are shown on Figure 6-20, and a representative cross section of upland components is provided on Figure 6-21. Sediment components are the same as for Alternative 7; therefore, refer to Figure 6-19 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.9.1 Removal of Upland PTWs

In this alternative, PTWs and overlying soil would be excavated, treated on-site, and reused as backfill. Excavation and on-site treatment was selected rather than excavation and off-site treatment based on the potential cost savings driven in large part by the expected designation of excavated soil as a RCRA hazardous wastes (which may include PTW soil containing benzene, based on its characteristics, and soil generated within the footprints of the North and South Sumps potentially containing RCRA-listed waste). *In situ* solidification of upland PTWs, which offers benefits and drawbacks compared to excavation, is described and evaluated in Alternative 7 (see Section 6.3.7).

The extent of soil removal and assumed construction methods are discussed below.

6.3.9.1.1 Areas and Volumes of Soil Removal

The lateral and vertical extent of PTWs is described in Section 3.5.

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[12] Reactive sediment capping is not included in Alternative 8 because sediment PTWs are removed.

Figure 6-20 depicts the area of soil to be removed, and Figure 6-21 depicts a representative cross section of the vertical extent of soil to be removed. The estimated extent of removal includes approximately 9.7 acres to a maximum depth of 34 feet for a total volume of 210,000 cy of upland soil.

6.3.9.1.2 Soil Removal Methods

Excavation would be performed as described in Alternative 4 (see Section 6.3.4.1.2) with excavation accomplished in the dry where possible using limited shoring and dewatering to facilitate construction, but deeper excavations may be performed in the wet to avoid extensive shoring and dewatering that may be required to depressurize the Deep Aquifer. Shoring and dewatering methods are discussed in Sections 6.3.4.1.3 and 6.3.4.1.4, respectively.

Because of the large area and variable depth of PTWs, the removal area would be divided into several discrete cells so that localized deeper PTWs may be removed by focusing more extensive shoring, dewatering, and/or wet excavation in these areas, and to maintain adequate area for stockpiling and construction support operations. Excavation cells and maximum excavation depths are shown on Figures 6-19 and 6-20.

Based on a maximum estimated rate of 400 cy per day for excavation and backfilling, removal of this area is estimated to take approximately 1.5 years. Additional time would be required for mobilization, Site setup, shoring and dewatering installation, and Site restoration. It is estimated that construction of this remedy component would take 2.5 years.

6.3.9.1.3 Shoring

Impermeable shoring walls would be installed around the perimeter of each excavation cell to prevent sidewall sloughing and to reduce the rate of construction dewatering. As described in Alternative 4 (see Section 6.3.4.1.3), it was assumed that temporary sheet pile walls (which could be removed and reused) would be required. The conceptual design criteria for sheet pile walls are described in Appendix F. Assumptions are summarized as follows for various excavation depths:

- **Up to 15 Feet Deep.** Cantilevered sheet pile walls with no tiebacks and a minimum embedment depth of approximately 35 feet (50 feet total depth);
- **Between 15 and 22 Feet Deep.** Anchored sheet pile walls with one row of tiebacks and a minimum embedment depth of approximately 20 feet (up to 42 feet total depth); and
- **Between 25 and 34 Feet Deep.** Anchored sheet pile walls with two rows of tiebacks and a minimum embedment depth of approximately 26 feet (up to 60 feet total depth).

The shoring wall cell perimeters are shown on Figure 6-20, and the estimated embedment depths are shown on Figure 6-21.

6.3.9.1.4 Construction Dewatering and Water Treatment

Soil excavation under Alternative 8 would be performed to minimize the need for construction dewatering; however, some dewatering would be needed to allow construction of shoring walls, and could also be performed where cost-effective to realize the advantages of dry excavation described in Section 6.3.4.1.2. Based on confined groundwater elevations in the Deep Aquifer, depressurization is required when dewatering to maintain excavation stability (e.g., prevent blow out of excavation bottom). A minimum depth to water of 19 feet is estimated to be required to install tiebacks for a 34-foot-deep excavation (see Appendix F). Additional detailed remedial design analyses to determine dewatering requirements would be performed after the ROD. Dewatering assumptions for this FS are as follows:

- **Cells less than 16 Feet Deep**. Shoring walls would be installed into the Deep Aquifer; however, no tieback anchors would be needed. Depressurization of the Deep Aquifer would not be necessary.
- **Cells greater than 16 Feet Deep.** Depressurization of the Deep Aquifer would be required to lower the aquifer to allow for installation of tieback anchors and maintain excavation stability. Depressurization would be conducted using dewatering wells screened in the Deep Aquifer and located inside the sheet pile cell.

Estimated cell depressurization flow rates are summarized in Appendix A. The maximum dewatering rate (Cell 7) is estimated to be 210 gpm. The estimates are for the flow rate required to maintain a depressurization at steady state, and initial flow rates may be initially higher. Dewatering estimates are preliminary for cost estimate purposes; additional testing and analysis are required prior to construction design.

Groundwater removed during dewatering activities would be treated and discharged, as described in Section 6.3.4.1.4.

For the estimated maximum flow rate under this alternative, discharge to Lake Washington is anticipated to be the most cost-effective option. It may also be necessary to treat arsenic in groundwater to meet surface water discharge requirements.

6.3.9.1.5 Management of Removed Soil

Excavated soil would be treated on site using *ex situ* thermal treatment. Because much of the soil to be treated is expected to have high organic content from organic silt, peat, and wood debris and high water content because of the shallow water table, additional testing would be needed to verify the effectiveness of thermal treatment at achieving soil cleanup numbers. For the purposes of this FS, it is assumed that thermal treatment would remove DNAPL but that the treated soil could still exceed cleanup numbers and require containment (such as capping).

Thermal treatment would be performed on site using propane-fired equipment. Contaminants in the offgas would be incinerated.

Treated soil would be used as Site backfill. Because soil that would be treated is predominantly fine-grained, it could not be placed in saturated conditions. Rather, imported backfill that can be compacted in saturated conditions (e.g., 1-inch rock) overlain with geotextile would be placed in cells not completely dewatered.

6.3.9.2 Alternative 8 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.8.3 and 6.3.8.4, respectively, below). The ENR area covers the same footprint as described for

Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.9.3 Alternative 8 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds cleanup numbers (outside of PTW areas) and where existing surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 7 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.9.4 Alternative 8 Removal of Sediment PTWs

Sediment removal for Alternative 8 is the same as described in Section 6.3.7.4 for Alternative 7. Alternative 8 includes dredging of the offshore (DA-1 through DA-5) and nearshore PTW areas (DA-6 through DA-8). Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade.

6.3.9.5 Alternative 8 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4). Areas excavated would not reguire a cap.

6.3.9.6 Alternative 8 Institutional Controls

Alternative 8 utilizes excavation of upland PTW and dredging of sediment PTW, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 8 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6; however it includes *ex situ* thermal treatment. The purpose of Alternative 8 is to remove all known PTW; however, contaminated soil and sediment remain in place. As a result, for Alternative 8 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been excavated are not expected to require a soil cap unless sampling of post-treatment backfill indicates exceedances of cleanup numbers.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of cleanup numbers. However, institutional controls for engineered sand caps, dredge residuals

covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. Cleanup numbers are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.

- Surface water – no fishing, no swimming, and no wading until cleanup numbers are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. However, most institutional controls in Alternative 8 will not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments will remediate in time.

6.3.10 *Alternative 9 – Solidification and Removal of Upland PTW and Contaminated Soil, and Removal of Sediment PTW and Contaminated Sediment*

Alternative 9 includes removal or treatment of soil and sediment that is likely to act as a long-term source of groundwater contamination above MCLs, including PTWs and soils and sediments contaminated with recalcitrant compounds (e.g., arsenic and benzo[a]pyrene). Low-permeability soils are present in much of the Shallow Alluvium; therefore, this alternative includes removal of Shallow Alluvium soils within the area where MCLs are exceeded[13], excluding benzene[14]. As described in Section 3.2, low-permeability soil layers are also present in the upper portion of the Deeper Alluvium, to a depth of at least 83 feet (as observed at boring SWB-8). Removal of low-permeability layers in the Deeper Alluvium is not included based on constructability concerns[15]. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Shallow upland soils (those that can be removed without extensive dewatering or shoring) would be removed. *In situ* solidification would be used to treat the deeper upland soils.

The objective of Alternative 9 is to remove or treat PTWs and to restore groundwater to the maximum extent possible. *In situ* solidification of deep soils was selected rather than excavation to reduce cost and improve implementability. Active polishing treatment

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[13] There is no naphthalene MCL and the naphthalene PRG is not based on an ARAR. As a result, groundwater exceeding the naphthalene PRG would not be targeted for treatment.

[14] Based on contaminant fate and transport modeling, benzene in fine-grained soils could biodegrade in less than 100 years, although the rate of biodegradation at the Site is uncertain. See Appendix A.

[15] Removal of soil in the Deeper Alluvium located within the arsenic plume would require excavation of soil and sediment near the shoreline to a depth of approximately 60 feet (see Figure 3-8).

(such as pump-and-treat) was considered to address this, but was not included in this alternative. (Polishing treatment is included in Alternative 10.)

Alternative 9 includes the following components:

- Removal of shallow upland PTWs and contaminated soil; on-site *ex situ* thermal treatment;
- *In situ* solidification of deep upland PTWs and contaminated soil;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary; removal/on-site *ex situ* thermal treatment of contaminated sediment;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 9 are shown on Figure 6-22 and representative cross sections are provided on Figures 6-23 and 6-24. Each component of the remedy is discussed below.

6.3.10.1 Areas and Volumes of Contaminated Soil

The area of soil to be removed or treated is shown on Figure 6-22. This area was estimated to include the following:

- The area of groundwater and porewater in the Shallow Alluvium exceeding MCLs for COCs (excluding benzene). All PTWs in the Shallow Alluvium would be addressed;
- The area of PTWs in the Deeper Alluvium (i.e., at BH-30); and
- The estimated area of benzo(a)pyrene exceeding its MCL in the Deeper Alluvium, as described in Section 3.5.

A representative cross section of the vertical extent of soil to be removed or treated is shown on Figure 6-23. Along this cross section, which is located in the middle of the Site, the majority of Shallow Alluvium soil would be removed or treated. In some areas south and north of this cross section where PTW, benzo(a)pyrene, and arsenic occurrences do not extend into the Deeper Alluvium, the lower portion of the Shallow Alluvium would not be treated. Average estimated excavation and solidification depths in different portions of the removal area are included in the volume calculations in Appendix E.

6.3.10.2 Alternative 9 Removal of Shallow Contaminated Soil

Alternative 9 assumes that upland Source Area soils are excavated to a depth of 15 feet.[16] Shallower soils would be excavated rather than solidified *in situ* for the following reasons:

- Removal of soil to 15 feet bgs would remove most of the upland PTWs and associated contaminant mass. By removing most of the upland PTWs rather than solidifying them, there is a greater likelihood that groundwater RAOs would be achieved.
- The expected unit cost of removal at shallow depths is expected to be similar to solidification because minimal shoring and dewatering would be required.

Figure 6-20 depicts a representative cross section of the vertical extent of soil to be removed. It is estimated that 340,000 cy of upland soils would be excavated under this alternative.

Soils above the static water table could be excavated using conventional earth-moving equipment, with little or no excavation dewatering required. Excavation sidewalls would be appropriately sloped to prevent sloughing and to preclude the need for shoring.

Soil excavation below the static water table would be accomplished by constructing temporary excavation cells, which would be sequentially dewatered, excavated, and backfilled. Conceptual design criteria for a sheet pile wall to facilitate a 15-foot-deep excavation include one row of tieback anchors and an embedment depth of approximately 35 feet bgs.

In some Site areas, particularly to the east away from the lake, it may be possible to excavate in the dry to 15 feet without the aid of shoring or cutoff walls; however, the preliminary construction dewatering analysis (see Appendix A) indicates the following:

- Without an impermeable perimeter wall around an excavation cell, predicted dewatering flow rates for a 1-acre cell range from approximately 100 gpm on the east side of the Site to more than 1,000 gpm at the shoreline; and
- With an impermeable perimeter wall, the predicted steady-state dewatering flow rate for a 1-acre cell is approximately 14 gpm.

Predicted flow rates for larger cells range from roughly 28 gpm for a 2-acre cell to roughly 56 gpm for a 4-acre cell.

For Alternative 9, it was determined that an average upland cell size of approximately 4 acres would minimize the amount of temporary shoring needed and would also maintain a reasonable dewatering flow rate, allowing sufficient room to conduct soil handling and stockpiling operations. Figure 6-19 shows the upland areas in which excavation cells are assumed to be constructed in Alternative 9, along with a conceptual layout of individual cells.

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[16] This is the estimated depth to which excavation is possible without dewatering to depressurize the Deeper Alluvium.

Because relatively low dewatering rates are anticipated, it is expected dewatering wells would not be required; rather, sumps and trenches would be installed at the base of the excavation to capture water draining from soils within the excavation area and seeping up from the base of the excavation.

Higher short-term flow rates would be needed to dewater soil to be removed (i.e., storage depletion) and to remove precipitation that falls within the excavation cell. For a 4-acre cell, a 2-inch rain event over a 24-hour period would result in approximately 150 gpm of additional flow. Temporary stormwater detention areas could be provided to reduce capacity needs from precipitation. The average dewatering flow rate for a 4-acre upland excavation cell, including precipitation and storage, is estimated to be approximately 70 gpm. Dewatering would need to be implemented during the entire duration of the excavation, solidification, and backfilling activities.

Groundwater removed during dewatering activities would be treated and discharged as described in Section 6.3.8.1.4. For the purposes of this FS, temporary discharge to Lake Washington is anticipated to be the most cost-effective option.

Construction would be sequenced with excavation starting on the eastern (upgradient) side of the Site and progressing west to avoid recontamination of remediated areas. The estimated construction timeframe for soil removal and backfill is approximately 8 years, broken down as follows:

- Design: 3 years;
- Material and equipment mobilization and construction of the groundwater treatment plant: 2 years; and
- Removal, treatment, and backfill of upland soils: 2.5 years, based on an estimated removal, treatment, and fill rate of 400 cy per day.

The total estimated water volume to be treated, based on the estimated duration of excavation and solidification and the average flow rate from each cell, is approximately 800 million gallons.

6.3.10.3 Alternative 9 Solidification of Deep Contaminated Soil

Upland Source Area soils below 15-foot depth would be solidified *in situ* in Alternative 9. Figure 6-23 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated soil volume requiring solidification is approximately 360,000 cy. Calculations are provided in Appendix E.

6.3.10.3.1 Soil Solidification Methods

Soils would be solidified *in situ* using large-diameter augers as described in Section 6.3.3.1.2 for Alternative 3. After solidification of a cell is complete, the remainder of the cell would be backfilled to restore the Site grade.

The estimated construction timeframe for soil stabilization is approximately 1.5 years, based on an estimated treatment rate of 600 cy per day.

6.3.10.4 Alternative 9 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.9.5 and

6.3.9.6, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.10.5 Alternative 9 Engineered Sand Cap

An engineered sand cap would be placed over sediments where surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line following sediment dredging. The cap would cover a smaller footprint than described for Alternative 2 because of additional nearshore dredging (see Section 6.3.9.6 below). The cap would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.10.6 Alternative 9 Removal of Contaminated Sediment

The sediment removal approach for Alternative 9 is the same as described in Section 6.3.7.4 for Alternative 7, except for the extent of dredging. Alternative 9 includes dredging of all the aquatic DNAPL areas (DA-1 through DA-8) and additional nearshore sediment area where sediment is potentially contributing to MCL exceedances. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade. The extent of sediment to be removed through the central portion of the Site is shown on Figure 6-22. The estimated extent of removal was calculated as described in Appendix E and includes approximately:

- 4.7 acres of mechanically dredged nearshore sediments, to a maximum depth of 27 feet below mudline;
- 3.3 acres of dredged sediments, to a maximum depth of 5.7 feet below mudline;
- 172,300 cy of sediment removal including:
  - 148,600 cy of nearshore sediments within the sheet pile wall; and
  - 23,700 cy of hydraulically dredged sediments.

As described in Section 6.3.4.7.2, sediment removal would be performed by hydraulic dredging and nearshore sediment removal would be performed by mechanical dredging within a sheet pile enclosure. Removal depths for Alternative 9 extend deeper than the PTWs. In the offshore aquatic DNAPL areas (DA-1 through DA-4), the target dredge depth is 2 feet below the observed PTW depth (i.e., 2 feet deeper than Alternatives 4 through 8).

In the nearshore areas (DA-6 through DA-8), the lateral dredge area was expanded to include the estimated area of groundwater and porewater in the Shallow Alluvium exceeding the benzo(a)pyrene MCL, which encompasses the extents of other Site COCs (excluding benzene) exceeding MCLs. The area of PTWs in the Shallow Alluvium is also encompassed within this area, with the exception of DA-7, which would also be excavated as part of this alternative. The nearshore target dredge elevation is generally the bottom of the Shallow Alluvium layer and the dredge depth varies with the thickness of this layer. The maximum nearshore dredge depth would be approximately 27 feet bss in approximately 15 feet of water, which is still within the capability (i.e., 50 feet) of most types of mechanical dredges.

The sheet pile enclosure for Alternative 9 would generally be similar to the one described for Alternative 4 in Section 6.3.4.7.4. However, due to considerably larger dredge depths for Alternative 9, significantly heavier sheet pile sections and slightly longer sheet piles would be required. Other significant differences are the wall alignment and length. The wall alignment is shown on Figure 6-22. The enclosure wall for Alternative 9 would be 1,500 feet long. Based on preliminary calculations, an AZ50 sheet pile section distributed in the United States by Skyline Steel (or similar section by another vendor with the same section modulus) would be adequate to withstand stresses within the sheet piles and limit deflections. The sheet piles would need to be embedded deep enough into the subsurface soils to provide adequate stability. Based on the preliminary calculations, the sheet piles would need to be approximately 60 feet long. The sheet piles and installation methods are assumed to be the same as for Alternative 2.

Based on an assumed sheet pile installation rate of 20 lf per day, sheet pile removal rate of 30 lf per day, and dredging rate of 400 cy per day, Alternative 7 sediment removal and backfilling would require approximately 153 weeks to implement.

6.3.10.7 Alternative 9 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above). Areas excavated would not reguire a cap.

6.3.10.8 Alternative 9 Institutional Controls

Alternative 9 utilizes excavation and in situ stabilization of upland PTW and contaminated soil, and dredging of sediment PTW and contaminated sediment, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 9 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6; however it includes *ex situ* thermal treatment. The following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been excavated are not expected to require a soil cap unless sampling of post-treatment backfill indicates exceedances of cleanup numbers.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of cleanup numbers. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated

or removed. Cleanup numbers are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.

- Surface water – no fishing, no swimming, and no wading until cleanup numbers are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. However, most institutional controls in Alternative 9 will not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments will remediate in time.

6.3.11 *Alternative 10 –Removal of Upland PTW, Sediment PTW, Contaminated Soil, and Contaminated Sediment*

The purpose of Alternative 10, similar to Alternative 9, is to treat PTWs and to restore groundwater, to the maximum extent possible.

Alternative 10 includes removal of soil and sediment that is likely to act as a source of groundwater contamination above MCLs, including PTWs and soils contaminated with recalcitrant compounds (e.g., arsenic and benzo[a]pyrene). Contaminated soil and groundwater in the Deeper Alluvium would be treated by groundwater pump and treat to speed restoration timeframe. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Alternative 10 includes the following components:

- Removal of all upland PTWs and contaminated soil; on-site *ex situ* thermal treatment;
- Groundwater treatment to address contamination remaining at depth below excavated areas;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary; removal of contaminated sediment and on-site *ex situ* thermal treatment;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 10 are shown on Figure 6-25, and a representative cross section of upland components is provided on Figure 6-26.

Sediment components are the same as for Alternative 9; therefore, refer to Figure 6-24 for illustration of components along a sediment cross section. Each component of the remedy is discussed below.

6.3.11.1 Alternative 10 Removal of Contaminated Soil

Removal would be conducted in the dry where practicable to minimize residual contamination. Contaminated soil excavation would require extensive shoring and dewatering. The extent of excavation is described below in Section 6.3.10.1.1.

6.3.11.1.1 Areas and Volumes of Contaminated Soil

The area of soil to be removed is shown on Figure 6-25. This area was estimated to include the following:

- The area of groundwater and porewater in the Shallow Alluvium exceeding MCLs for COCs (excluding benzene). All PTWs in the Shallow Alluvium would be addressed;
- The area of PTWs in the Deeper Alluvium (i.e., at BH-30); and
- The estimated area of benzo(a)pyrene exceeding its MCL in the Deeper Alluvium, as described in Section 3.5

A representative cross section of the vertical extent of soil and sediment to be removed is shown on Figure 6-26. Along this cross section, which is located in the middle of the Site, the majority of Shallow Alluvium soil would be removed. In some areas south and north of this cross section where PTWs, benzo(a)pyrene, and arsenic occurrences do not extend into the Deeper Alluvium, the lower portion of the Shallow Alluvium would not be removed. Average estimated excavation depths in different portions of the removal area are included in the volume calculations in Appendix E.

The estimated extent of each area of excavation was calculated as described in Appendix E, and includes approximately 14 acres of upland soils, to a maximum depth of 40 feet bgs for a total volume of 705,000 cy of upland soils.

6.3.11.1.2 Soil Excavation above the Static Water Table

Soils above the static water table would most likely be excavated using conventional earth-moving equipment, with little or no excavation dewatering required. Excavation sidewalls would be appropriately sloped to prevent sloughing and to preclude the need for shoring.

6.3.11.1.3 Upland Excavation Cells

In-the-dry excavation of upland soils below the static water table would be accomplished by constructing temporary excavation cells, which would be sequentially dewatered, excavated, and backfilled. An excavation cell's perimeter would consist of an impermeable wall. The wall would serve the following two purposes:

- To shore the excavation sidewalls (i.e., prevent sidewall sloughing); and
- To limit water flow into the excavation cell, reducing the amount of dewatering needed to maintain dry conditions.

For the purposes of evaluating this alternative, temporary sheet pile walls (which can be removed and reused) were identified as the likely least-cost option. Sheet pile wall conceptual design criteria for a 40-foot-deep excavation include three rows of tieback anchors[17] and a minimum embedment depth of approximately 65 feet bgs. Preliminary shoring design considerations are described in Appendix F.

Conventional land-based excavation equipment would likely operate inside the excavation cells; therefore, the cells must be large enough (in areal extent) to accommodate this equipment. In addition, larger cells translate into fewer linear feet of temporary sheet pile wall that must be installed and subsequently removed; however, dewatering requirements place a practical limit on cell size (i.e., dewatering flow rate increases with increased cell size). The rate at which groundwater must be pumped from the cell to maintain conditions needed for in-the-dry excavation can be reduced by increasing the sheet pile wall embedment depth, but that also has practical limits as well as significant cost implications. A preliminary cost-benefit analysis (see Appendix E) was performed using the hydraulic groundwater flow model described in Appendix A to estimate required dewatering flow rates for a range of cell areas and sheet pile embedment depths. This analysis identified a cell size of approximately 1 acre and a sheet pile embedment depth of 95 feet (30 feet deeper than the average depth required for shoring purposes) as the most economical design. Sheet piles of this length are non-standard and would require special transport and handling considerations. Additionally, vibratory hammer and/or high-pressure jetting at the toe of the piles may be required to achieve the target depth.

Figure 6-25 shows the upland area in which excavation cells would be constructed in Alternative 10, along with a conceptual layout of individual cells. A cross section showing conceptual shoring wall embedment of a representative cell is provided on Figure 6-26. The cells would be large enough so that ramps could be constructed inside the cells to allow excavated soil to be direct-loaded into trucks for transport out of the cell. This method would likely be used to remove most of the soil from a cell. During the final stages of cell excavation, however, internal ramps would no longer be an option. It is assumed that a crane would then be used to place an excavator inside the cell. Soil could then be transported out of the cell using a clamshell bucket or conveyor belts. A temporary working surface such as a structural mat would likely be required at the base of the excavation because of the soft Site soils.

After source area soils/sediments are removed from the cell, clean fill (either treated Site soil/sediment or imported material) would be used to restore the original Site grade. Each cell would be backfilled only after excavation of the entire cell is complete, to minimize the risk of recontaminating clean fill. Fill would be placed in lifts and compacted. After the grade inside the cell is restored, the sheet pile wall segments that do not form a portion of a subsequent (adjacent) cell wall would be removed and reused elsewhere on the Site.

Construction would be sequenced with excavation starting on the eastern (upgradient) side of the Site and progressing west to avoid recontamination of remediated areas. The

[17] Whalers and struts could also be used to brace the sheet piling; however, the relatively large cell size would likely make tiebacks more cost-effective.

estimated construction timeframe for soil removal and backfill is approximately 10 years, broken down as follows:

- Design: 3 years;
- Material and equipment mobilization and construction of the groundwater treatment plant: 2 years; and
- Removal, treatment, and backfill of upland soils: 5 years, based on an estimated removal, treatment, and fill rate of 400 cy per day.

6.3.11.1.4 Cell Dewatering and Water Management

To allow for in-the-dry excavation, a dewatering system would be installed within each excavation cell. The dewatering system would consist of the following:

- Sumps and trenches at the base of the excavation, to capture water draining from soils within the excavation area; and
- Dewatering wells, to lower the water table within the cell to below the base of the excavation. The wells would be screened in the Deeper Alluvium.

As the excavation deepens, dewatering wells would need to be either protected or decommissioned and reinstalled. The number of wells and required flow rates would vary based on the cell location as well as the stage of excavation (excavation depth) within the cell. Groundwater removed during dewatering activities would be treated and discharged as described for Alternative 8 in Section 6.3.8.1.4. For the purposes of this FS, temporary discharge to Lake Washington is anticipated to be the most cost-effective option.

The maximum estimated dewatering flow rate for an upland excavation cell is approximately 280 gpm for a 1-acre cell at the shoreline. Additional capacity would be needed to allow for initial cell drawdown and to treat precipitation falling within a cell. Dewatering volume calculations are provided in Appendix A. The total estimated water volume to be treated, based on the estimated dewatering duration and average estimated flow rate of 220 gpm in the upland, is 600 million gallons.

6.3.11.1.5 Management of Removed Soil

Excavated soil would be treated on-site using thermal treatment as described in Section 6.3.8.1.5 for Alternative 8. Treated soil would be used as Site backfill. Because much of the soil to be treated is expected to have high organic content from organic silt, peat, and wood debris and high water content because of the shallow water table, additional testing would be needed to verify the effectiveness of thermal treatment at achieving cleanup numbers in soil and groundwater. For the purposes of this FS, it is assumed that thermal treatment would remove DNAPL and achieve levels protective of groundwater, but that the treated soil may still exceed soil cleanup numbers and require containment (such as capping).

For the purposes of this FS, it is assumed that thermal treatment would be performed on-site using propane-fired equipment. Contaminants in the offgas would be incinerated.

6.3.11.2 Alternative 10 Groundwater Treatment

Groundwater pump and treat technology would be implemented to address contamination remaining at depth below the excavated areas after removal of contaminated soils and sediments is completed. The objectives of the pump and treat system would be to increase flushing of the Deeper Alluvium and reduce the Deep Aquifer restoration timeframe.

The pump and treat system would consist of a groundwater extraction system, an on-site treatment plant, and a means of handling the treated water (e.g., reinjection or discharge to Lake Washington). A conceptual design and proposed implementation strategy for groundwater extraction is discussed in Section 6.3.10.2.1. Elements of extracted groundwater management are discussed in Section 6.3.10.2.2.

6.3.11.2.1 Groundwater Extraction

To develop a conceptual design for the groundwater extraction system, the Site groundwater hydraulic model and contaminant fate and transport model were used. The groundwater model and the development of the conceptual design for the Alternative 10 groundwater extraction (pump and treat) system are described in Appendix A. A summary is as follows:

- The hydraulic model was used to determine the minimum flow rate, and a conceptual layout of pumping wells was developed that would capture groundwater within the upland portion of the groundwater plume.
- The hydraulic model was used to evaluate the pumping system's ability to capture the plume beneath the lake by increasing flow rates and observing the resulting capture zones.
- The contaminant fate and transport model assessed representative heterogeneous layers of the Deeper Alluvium and evaluated the pumping system's ability to reduce restoration timeframe in these layers by increasing flow rates. This was performed by observing the effect of increasing flow rates on the predicted time to achieve MCLs at representative points in the upland and offshore portions of the Deeper Alluvium.

Preliminary modeling results were used to optimize the conceptual design of the Alternative 10 groundwater extraction system as follows:

- Extracting a total of approximately 90 gpm from six extraction wells would capture the upland area of groundwater exceeding MCLs.
- The capture zone for the proposed pumping system is predicted to extend to a maximum of 100 feet offshore.
- Increasing the total flow rate slightly reduces the restoration timeframe within permeable layers of the Deeper Alluvium but does not significantly increase the offshore capture of the groundwater plume or reduce the Site overall restoration timeframe.

The estimated time to construct the pump and treat system is 6 months. Monitoring would be performed after pump and treat performance monitoring indicates remediation goals in the upland and sediment areas are achieved and the pump and treat system is turned off. Groundwater and porewater monitoring would be performed at monitoring wells in the Shallow Alluvium and Deeper Alluvium to evaluate whether groundwater concentrations rebound above cleanup levels. For cost estimating purposes in the FS, the assumed duration of pump-and-treat system operation is 100 years.

6.3.11.2.2 Management of Extracted Groundwater

The treatment system would be similar to that described for the construction dewatering program, except no DNAPL separation would be required as all free-phase DNAPL is assumed to have been removed during excavation. In addition, equipment capacities would be less, as the estimated system flow rate is less than the maximum flow rate needed for construction dewatering.

6.3.11.3 Alternative 10 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with an engineered sand cap (see Section 6.3.10.4 below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.11.4 Alternative 10 Engineered Sand Cap

An engineered sand cap would be placed over sediments where surface sediment concentrations are approximately greater than 2 times the BTV along the inner harbor line following sediment dredging. The cap would be placed over the same areas as for Alternative 9 (see Section 6.3.9.5). The cap would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.11.5 Alternative 10 Removal of Contaminated Sediment

Sediments containing PTWs and potentially contributing to MCL exceedances would be removed. The sediment removal extent and approach for Alternative 10 is the same as described in Section 6.3.9.6 for Alternative 9.

6.3.11.6 Alternative 10 Upland Cap

Areas where COCs exceed cleanup numbers in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above). Areas excavated would not reguire a cap.

6.3.11.7 Alternative 10 Institutional Controls

Alternative 10 utilizes excavation of upland PTW and contaminated soil, and dredging of sediment PTW and contaminated sediment, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 10 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6; however it includes *ex situ* thermal treatment. The following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been excavated are not expected to require a soil cap unless sampling of post-treatment backfill indicates exceedances of cleanup numbers.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any

activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of cleanup numbers. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. Cleanup numbers are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.

- Surface water – no fishing, no swimming, and no wading until cleanup numbers are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are not enforceable. However, most institutional controls in Alternative 10 will not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments will remediate in time.